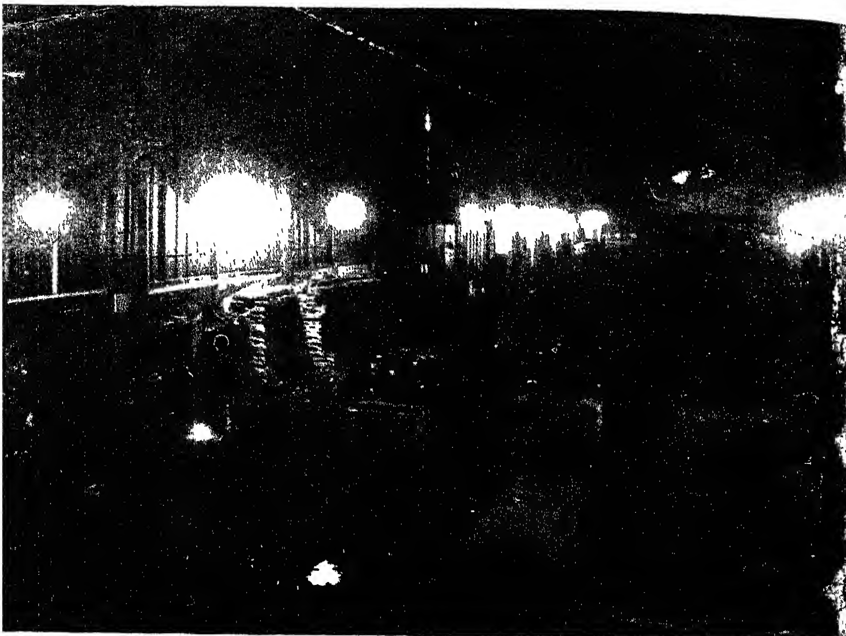
9(44)

MODERN INDUSTRIAL LIGHTING



BLESSINGS OF SCIENTIFIC LIGHTING

Two scenes showing the same foundry taken from the same place with the sa camera and the same developing treatment, before and after the installation o a modern lighting system

MODERN INDUSTRIAL LIGHTING

by

G. BERNARD HUGHES
AUTHOR OF "DRY BATTERIES"

With 63 Illustrations

HUTCHINSON'S
SCIENTIFIC & TECHNICAL PUBLICATIONS
LONDON : NEW YORK : MELBOURNE

Made and Printed in Great Britain at St. Albans by *The Mayflower Press* (of Plymouth). William Brendon & Son, Ltd.

CONTENTS

CHAPTER		PAGE
I.	Facts for Lighting Engineers	7
II.	The Purpose of Lighting	12
III.	Glare	16
IV.	Lighting and Safety	23
V.	Sources of Light	30
VI.	Fluorescent Tubular Lamps	36
VII.	Industrial Requirements	45
VIII.	Design of Lighting Installations	53
IX.	Maintenance	71
X.	Statutory Regulations	81
XI.	Production, Assembly and Inspection Processes	90
	Appendices	99
	Index	123

LIST OF ILLUSTRATIONS

Diagrams in Text

	PAGE
Rating Schedule used in the Selection of Industrial Lighting for Specific Jobs	9
Mazda Fluorescent Lamp and Auxiliaries	38
Stroboscopic Effect	43
Value of Voltage with respect to Time in an Alternating Current Circuit	43
Resultant Intensity Variation with a Two-phase Fluorescent Lighting System	44
Time-intensity Curve showing Elimination of Stroboscopic Effect	44
R.L.M. Dispersive Reflection	58
Distribution of Light with Dispersive Reflectors	59
Concentrating Reflector	60
Distribution of Light with Concentrating Reflectors	61
Longitudinal Spacing of Vertical Elliptical Reflectors	61
Latitudinal Spacing of Vertical Elliptical Reflectors	62

FIG.		PAGE
13.	RATIOS FOR LIGHTING FROM SIDES OF WORKSHOPS . .	62
14.	RATIOS FOR LIGHTING VERTICAL SURFACES	63
15.	DIFFUSERS	64
16.	LIGHT DISTRIBUTION WITH DIFFUSERS	65
17.	SPACING AND MOUNTING DATA FOR EXTENSIVE TYPE OF LOCAL LIGHTING REFLECTOR	66
18.	SPACING AND MOUNTING DATA FOR INTENSIVE TYPE OF LOCAL LIGHTING REFLECTOR	67
19.	PARABOLIC ANGLE REFLECTORS	68
20	SPACING AND MOUNTING DATA FOR DISTRIBUTING REFLECTORS	70
21.	PERCENTAGE VARIATION CURVE	71
22.	DIAGRAMMATIC REPRESENTATION OF ONE LUMEN . . .	101

Half-Tones

BLESSINGS OF SCIENTIFIC LIGHTING	*Frontispiece*
THE LIGHT METER	BETWEEN PAGES 24 *and* 25
AN OFFICE	BETWEEN PAGES 24 *and* 25
A MACHINE SHOP	BETWEEN PAGES 24 *and* 25
LEATHER SOLES STORE AT A BOOT AND SHOE FACTORY .	BETWEEN PAGES 24 *and* 25
PRESS SHOP AT A CYCLE FACTORY	BETWEEN PAGES 24 *and* 25
COMPOSING ROOM OF A NATIONAL NEWSPAPER . .	BETWEEN PAGES 24 *and* 25
A POTTERY SPRAYING DEPARTMENT	BETWEEN PAGES 24 *and* 25
A NEWSPAPER PRESS ROOM	BETWEEN PAGES 24 *and* 25
WOODWORKING DEPARTMENT OF A RAILWAY CARRIAGE SHOP	BETWEEN PAGES 24 *and* 25
AN ENGINEER'S HEAVY ENGINEERING DEPARTMENT .	BETWEEN PAGES 24 *and* 25
CLEANING AND PRESSING AT A DYE WORKS . .	BETWEEN PAGES 24 *and* 25
SORTING AND MARKING AT A LAUNDRY . . .	BETWEEN PAGES 24 *and* 25
AN ENGINEER'S DRAWING OFFICE	BETWEEN PAGES 24 *and* 25
AIRCRAFT ASSEMBLY WORKS	BETWEEN PAGES 24 *and* 25
A CHEMICAL WORKS	BETWEEN PAGES 24 *and* 25
AN ENGINEER'S FOUNDRY	BETWEEN PAGES 24 *and* 25
EXAMPLES OF INDIVIDUAL REQUIREMENTS OF SPECIFIC OPERATIONS IN FACTORY AND WORKSHOP . .	48 ,,

CHAPTER ONE

FACTS FOR LIGHTING ENGINEERS

IN lighting more than in any other branch of industrial equipment, modern experts have achieved remarkable success It is the purpose of this book to indicate the ways in which well-planned, well-executed lighting systems can ensure maximum speed, efficiency and health in every type of factory.

The following chapters deal with every aspect of the subject from the viewpoint of the lighting technician, the factory executive and the factory operator There is one other viewpoint, too, and this may well serve as a preliminary introduction Modern lighting engineers have something essentially worth selling: too few have really tackled this problem of salesmanship Yet in almost every case the extent to which they are asked to bring illumination in a factory up to statutory efficiency and beyond depends upon the way they put across their new methods and new ideals

The essential basis for their salesmanship must be an understanding of the factory executive's requirements and the reasons that have prompted him to wish to better his present installation. Generally, his reasons are: to reduce both initial and operating costs of lighting by the use of more efficient equipment exactly suiting the factory's needs; to check up on his own rather hazy theories, and to be given the benefit of modern experiment which will give him reliable information and statistics concerning his own employees' needs; to possess a comprehensive maintenance system so that the initial advantages will be assured for a number of years ahead.

In other words, he is generally an ideal customer for a lighting engineer who is sure of the worth of his goods. Widespread reports on such 'miracles' as fluorescent lighting have prepared him for changes In so far as expense allows, he is concerned in bringing his plant up to date, and he looks upon his factory as setting the lighting expert a peculiar, individual problem. And in this he is generally right.

How can he best be met by the illuminating engineer—the man upon whom eventually every development of industry depends for its popularity?

First, by thorough analysis of the factory's individual problem. There must be generalization, no fluffy sales talk. There is always available the direct-reading lightmeter; take it to any poorly-lit area in a factory and its proof is wholly convincing. No live factory executive will accept such an indisputable indication of efficiency-leakage: immediately he will want a thorough, complete analysis of his present lighting system, covering all its advantages, all its failings. And, after that, an individual plan to answer his individual needs.

Fluorescent tubes or incandescent equipment, for instance, may appear equally efficient to light a machine. But always there is the construction of the building to be taken into consideration, the class of employees, even the personality of those authorizing the change. The industrialist has the right to demand this individual experiment and advice.

He has, too, the right to select a solution that appears to him wholly

logical. Remembering that he will expect not only greater efficiency but a reduction in operating costs, there is a sales appeal not to be overlooked in the application of concentrated lighting. A system of 200-watt lamps on ten-feet centres may ensure that a factory has an impressive general brightness, yet waste the greater part on non-productive areas while the productive areas suffer from completely inadequate illumination. It's illogical. It's bad business. It is, unfortunately, still too typical of the lighting suggestions made by the less enterprising.

The third of the factory executive's stipulations stated above was durability—initial performance assured for several years. He is willing enough to pay for a job in which provision is made for easy, economical maintenance rather than for something which begins by looking good but quickly loses its efficiency.

Summed up, this new approach means :

(*a*) Stimulating the prospective customer's interest in productive lighting by supplying him with *complete* information.

(*b*) Providing the right foundation for immediate sales with careful, comprehensive plans.

(*c*) Ensuring continued satisfaction by giving full attention to the question of maintenance—and so, especially in large, ever-changing factories, ensuring continued sales.

Consider a few examples of how this works out. That well-planned approach is illustrated in a certain aero-engine works that had so little natural light in two of the shops that they were known as 'the dungeons.' A survey of the lighting conditions with a lightmeter showed that the average illumination was 6·8 foot-candles—rather more than regulation requirements. But at a certain point in the operation of one group of machines there existed a shadow about two inches wide which ran the entire length of the working area, so that the intensity at this point while work was being done fell to less than one-half foot-candle. It was quite evident that this shadow must be eliminated if any improvement was to be effected.

After careful analysis an indirect lighting system was recommended. A trial installation was made over one pair of machines so arranged that it was possible to secure any lighting intensity from 8 foot-candles to 42 foot-candles. A check on production showed that 15 foot-candles was the most profitable illumination level. Under these conditions the production was increased 12 per cent. This was the intensity of the system permanently installed.

One startling fact brought out in this test was that at 8 foot-candles, only 1·2 foot-candles above the original intensity, the increase in production was 7·7 per cent., due to the superior quality of the lighting which relieved the strain on the eyes and made seeing easier. These results were accomplished on an automatic machine which was running on a constant speed for 70 per cent. of the time. Thus only 30 per cent. of the total time was available for light to speed up work. Accurate information was obtained by a foreman equipped with a lightmeter and a stop watch. Each operation was broken down into its component parts, and the new lighting carefully planned to give the best seeing conditions.

This instance is most interesting, not merely because of the technical aspects of the problem, but more because the firm concerned acted immediately on the facts placed at their disposal ; and they still put into practice these principles of better lighting. This firm carried out the recommenda-

tions of the professional illuminating engineer in spite of the fact that the new equipment cost many times what they were in the habit of paying, and the increase in lighting cost was of the order of 500 per cent.

Recently a large mill engaged in the weaving of cotton was equipping a new weaving shed with 250 looms. Their chief engineer called in a professional illuminating engineer and asked for the best loom lighting that the knowledge of the art could produce. The existing lighting in the other weaving sheds in the mill consisted of general lighting units, placed with little regard to the production areas. A test with a lightmeter showed that in many cases one loom had twice the illumination of the one next to it

RATING SCHEDULE USED IN THE SELECTION OF INDUSTRIAL LIGHTING FOR SPECIFIC JOBS

	Good	*Medium*	*Poor*
1. Glare and shadow effect . . .			
2. Uniformity of light distribution . .			
3. Ease and cost of maintenance . .			
4. Mechanical construction (rugged or otherwise). Presence or absence of moving parts			
5. Colour value			
6. Cost and ease of installation (note weight of wiring, etc.) . . .			
7. Efficiency (foot-candle intensity) .			
8. Appearance (favourable or non-favourable)			
9. Manufacturer			
10. Initial cost			

Fig. 1

The first decision was to correct the error in spacing and mounting height. The next step was to select the type of unit to be used. Six groups of four looms each were equipped with a different type of lighting unit. Comparative tests were made and a rating given to each unit according to a standard scale. The scale used is shown in Fig. 1. As a result of this study a standard 500-watt R.L.M. reflector with a disconnecting hanger was chosen as the most suitable unit.

This step complete, a tentative lighting layout for four looms was made, and a test installation built in such a way that the position and height of each unit could be varied. Two experienced weavers were then called upon to assist and, to ensure absence of objection shadows (both of machine parts and operator), and uniform distribution of light in the working area, the exact position of the lighting units was determined by experiment.

[illegible] and wiring layout [illegible] satisfactory lighting [illegible] constant voltage, each branch [illegible] 600 [illegible] useless [illegible] Each [illegible] 20 degrees in any direction [illegible] sockets.

[illegible] decided upon a [illegible] lighting problem con[illegible] success of this method of [illegible] have since relieved [illegible] on [illegible].

[illegible] (Standards of Lighting) Regulations [illegible] Ministry of Labour and National Service, a huge foundry [illegible] were entirely inadequate to meet [illegible] the lighting of a horizontal boring [illegible] for [illegible] locomotive cylinders.

[illegible] practice [illegible] to twist an extension lamp [illegible] the tool [illegible] to be able to [illegible] the [illegible] when the tool reached the [illegible] This problem was solved immediately by mounting [illegible] spot light (equipped with a dust proof cover) about fifteen feet [illegible] and directing the light beam to follow the tool throughout its travel. The [illegible] over 70 foot candles in the critical working area and [illegible] the [illegible] trouble.

The solution of this one job led to a complete survey and analysis of the whole foundry. [illegible] were carried out in accordance with a comprehensive plan [illegible] operation was treated as an individual problem. For example, two bays, [illegible] one hundred by three hundred feet, are devoted to the [illegible] of castings. Individual pieces frequently weigh over 100 tons. [illegible] employed 200 watt portable standard lamps which [illegible] 20 foot candles on the work. The general illumination was of the order of 1 foot candle. The existing general lighting units were useless because of the unusual mounting height of 50 feet and the [illegible] dust and dirt conditions.

Accordingly [illegible] 1000 watt [illegible] was constructed, consisting of a [illegible] mirrored glass, floodlight reflector in a spun [illegible] floodlight cover. This newly designed [illegible] control of the [illegible] on the work. Maintenance costs [illegible] and the use of portable lamps has been abandoned except in the case of large closed castings.

A large ball bearing manufacturer, engaged in consolidating two plants into one, called upon an illuminating engineer for advice. This engineer spent three days in the shops watching men at work. Due to the urgency of the job, a tentative layout was made immediately, allowing a suitable factor of safety to cover such changes as might be necessary when each job was analysed in detail. The first department analysed was the cage department. A flexible trial installation of mercury discharge lamps was installed.

The lighting engineer spent a considerable time in the department adjusting the illumination to suit the various jobs being carried out, before beginning the permanent installation. In one shop the foreman refused the proposed layout and had one of his own design installed. Within a few weeks the new installation was removed at his own request and replaced with an accurately engineered job. In many of these operations the work

has a tolerance of one ten-thousandth part of an inch. Thus accurate lighting proved its value when accurate manufacturing was essential.

These examples are typical: they indicate that properly designed and installed industrial lighting can be entirely successful for both illuminating engineer and industrialist. The method followed is substantially the same in all cases and consists in:

1. Making satisfactory contact with the executive who has the authority to approve appropriations. The advantages the firm can obtain for a reasonable expenditure are emphasized.

2. Arranging if possible for some recommendation to be made at once concerning one operation which will prove a striking example of possible improvement and the value of planned lighting. This is the surest way to secure an order for surveying and designing lighting systems for the whole plant.

3. Listing with honest accuracy advantages as well as defects in the present lighting system, individual attention to each process being the secret of success. To get near ideal illumination on each productive area the lighting expert must secure each employee's co-operation. When he realizes that the aim is to help him, preserve his sight, improve his work, he is ready to help. Only by watching every process can the man's needs be appreciated and the best way devised to meet them.

Only secondary to this all-important localized lighting comes the consideration of a good plan for any necessary general illumination.

4. Remembering that all layouts must plan for several years' continuous satisfaction and therefore stipulating for:

(*a*) No wire smaller than No. 12. Wire capacity to allow for a 50 per cent. load increase without an excessive voltage drop.

(*b*) Fuseless panel cut-outs.

(*c*) Lamps and reflectors mounted high enough to be difficult to reach.

(*d*) Stem suspension.

(*e*) Sturdy equipment made by a reputable manufacturer.

More than that, when the immediate alteration covers only a part of the plant, it is a wise policy to provide a co-ordinated specification for the whole, so that all present improvements will fit in with the later developments as steps in a logical plan.

Always the emphasis is on continued benefit to the customer. Indeed it is far more satisfactory to the salesman as well as to the customer to have improvements introduced slowly but thoroughly with every detail right, than to have a larger undertaking carried out at scamped, cut-price rates.

For it cannot be too strongly stressed that the life of the former method is continuous satisfaction. Provide a customer with lighting that will give of its best over a period of years, low maintenance costs, a continuous planned improvement based on an adequate initial outlay, and a reasonable maintenance schedule, and he is likely to be well satisfied.

CHAPTER TWO

THE PURPOSE OF LIGHTING

NEARLY all sources of light emit radiant energy at wave-lengths both longer (infra-red) and shorter (ultra-violet) than those visible to our eyes. These all affect human health and must be controlled. The main concern of this book, however, is in those rays which possess the strange faculty of evoking in our eyes the sensation of light, enabling us to see.

Light, being a subjective sensation, cannot be objectively measured. All the 'lumens,' 'foot-candles,' etc., really measure certain amounts of radiant energy at certain wave-lengths, and these are expected to evoke equivalent sensations in the eyes of the average man. Because seeing is a mental act based on a physiological process, there can be no hard-and-fast rules for illumination, and no cure-alls.

The human eye was developed by natural light for millions of years before it became human, and for scores of millions before it became an eye. It is therefore wise to follow natural conditions as closely as possible. The almost unlimited possibilities of artificial illumination should not lead to a deviation from this rule without good reason, and certainly not in rooms which are in permanent use.

We did not develop the ability to see just for fun, but in order to grab, and to avoid being grabbed. The good, the true, and the beautiful light is the light that enables us to perceive real bodies. We want to perceive their exact size, shape and distance, and perceive them safely, easily and quickly.

Primarily we do not see bodies, but just surfaces, varying in shape, brightness and colour, and laid out on the inside of a perisphere, of which our eye is the centre. Because every surface in this visual perisphere emanates light, control of light means control of the entire luminous environment, though only a part of it is visible at one time. This part, called the visual field, centres around the axis of vision, extending about 100 degrees to either side, and 90 to 70 degrees upwards and downwards.

In the process of perception shadows are the main guides. Two extremes must be avoided: a perfectly uniform brightness (and colour) of the entire visual field would make all objects invisible. With the limited means formerly available this was not likely to occur, but with modern methods of illumination it has become a danger to be guarded against. On the other hand, excessive contrasts make discrimination of details in the shadow of n[illegible]le.
other [illegible] di[illegible]
impossi[illegible] [illegible]ntative [illegible]ances is perception not entirely dependent on mental
Only at close distances is perception not entirely dependent on mental processes translating two dimensional images into bodies, but receives three-dimensional impressions by the physiological acts of focusing and convergence. Changes in focus are noticeable at distances under twenty feet, while convergence of the two eyes operates even at distances of several hundred feet. Converging and focusing apparatus co-operate automatically adapting the eyes to the distance of the object.

The eyes having been developed for frequent changes in distance adaptation, mostly for objects far away, it is little wonder that eyestrain is c[illegible] continuous adaptation to the tasks imposed by civilization. The [illegible] [illegible]ooking at distant objects from time to time, even if [illegible]

only for a few seconds. This relaxation is usually achieved by looking out of the window.

Generally this physiological function of the distant view is overlooked and the desire to 'look out' is attributed to a mental urge only. Hence ugly views are deemed worse than useless and are excluded. They do afford some relaxation, however, though this may sometimes be partially offset by depressing effects on the mind.

Certainly the mental influence of a cheerful view is also important; but if it were to be considered alone, an actual distant view might be replaced by a mirror or a picture. Instead of affording relaxation from near-vision adaptation, however, this makes matters worse by causing the eyes to focus for distant vision. It results in a blurred image, causing serious eyestrain.

The popular preference for the traditional window is not to be hastily discarded, even in factories, as a sentimental hangover from the pre-electricity age. The possibility for distance adaptation is a constituent element of good-seeing.

Without a view from a window, a degree of distance adaptation is possible in factory workshops having large floor areas, provided that the view of the end of the shop is not obstructed by glare. Therefore equalization of surface brightness is far more important with artificial lighting than it is with daylight received through windows. At distances of less than twenty feet no satisfactory visual relaxation is possible; it is hardly an accident that rooms are generally considered small if their greatest dimension does not attain this minimum.

In daytime, light may be received from the sun and from the sky in greatly varying proportions. On a clear day, with the sun at zenith, about six times as much light is received from the sun than from the entire hemisphere of the sky; with the sun standing ten degrees above the horizon, the amounts from both sources are about equal. A hazy sky is several times brighter than a clear one, and of the same white colour as the sun, while the light from a clear sky is poor in yellow and red rays, and calls for correction by addition of reflected sunlight.

The most striking difference between the various sources of light is their colour. Colour is the sensation by which our eye registers differences in wave-lengths of radiant energy; sensitivity to these differences varies widely in various individuals. Furthermore, in one individual, identical sensations may be evoked by an infinite number of combinations of various wave-lengths.

At low brightness our eyes are more sensitive to short—blue and violet—rays than to long ones. Therefore so-called 'daylight' lamps are white only at high brightness, but bluish when they are dim, and should be used with discrimination. With artificial light it is generally safer to err towards the longer than towards the shorter end of the daylight spectrum.

Incandescent lamps have a continuous spectrum similar to that of the sun, but with a greater percentage of long rays. With increases in temperature the peak moves towards the shorter rays. The hotter the filament, the cooler—and brighter—the light; therefore high wattages are much more economical than low ones. In order to match daylight, however, even with the highest wattage, more than three-quarters of the total light of the bulb has to be filtered out. This means not only increased expenses for current, but also increased heat.

The old carbon-arc lamp produces a fairly white light. Cored with certain compounds, it emanates a spectrum more nearly like the

to other artificial sources. As the flicker and noise that once eliminated it from the field of practicability have been overcome, the carbon-arc may possibly come back.

The neon, sodium, mercury-vapour and other enclosed arc-lamps have discontinuous spectra, consisting of a number of 'lines.' These are strongly modified by changes in voltage and pressure, becoming more continuous as pressure increases.

Discontinuous spectra may cause unpleasant surprises. A light resembling daylight when reflected from white surfaces, may strongly affect some other colours. This is the case with the low-pressure mercury arc, which is overdosed with blue and yellow, but poor in green, and deficient in red: against this is the fact that the lamps are cool.

Fluorescent tubes, based on the mercury arc, share these characteristics, but modify them by filtering through the fluorescent coating. Addition of warm incandescent light to the spectrum of mercury-vapour or fluorescent lamps is usually the best way to match the colour of daylight.

Light of a single wave-length—monochromatic light—has the advantage of eliminating the phenomenon known as chromatic aberration, which slightly blurs our vision in any light having a continuous spectrum, such as daylight. Actually objects can be seen more clearly in sodium light, which is monochromatic yellow.

Both translucent coloured bodies and reflecting coloured surfaces act as selective filters, absorbing all light waves of other colours than their own. They produce coloured light by deduction, with a corresponding loss of brightness. The loss amounts to about 50 per cent. for most pale colours and for pure yellow, and to about 90 per cent. and more for saturated colours.

Mixing the light of luminescent gases of different colours produces colour by addition, the resulting brightness equalling the sum total of the brightest of the sources. This opens up new perspectives: perhaps it will soon be possible to mix light to suit personal tastes.

Care must be taken to avoid twilight, which is light from two sources of different colour, which have not mixed. It occurs frequently when the blue light of the evening sky meets the yellow light of an incandescent bulb.

Where artificial light is used alone, much is to be said for the natural continuous spectrum of the filament lamp, which is identical with the spectrum of the sun seen through a thick layer of air.

The human eye has an almost unlimited ability to adapt itself to brightnesses varying from one to ten million units, but efficiency and ease of seeing increase greatly with increasing brightness. The improvement is very great up to 15 or 20 foot-candles, substantially up to 50 foot-candles; above this limit it decreases, but remains distinctly noticeable.

These facts furnish the basis for standards accepted by lighting engineers as desirable for artificial lighting in factories: general illumination, 15 to 20 foot-candles for ordinary jobs, about 50 foot-candles where work is done on close tasks such as small assembly work, plus local lighting where higher brightness is needed. These brightnesses can easily be achieved at reasonable cost with both incandescent and fluorescent light installations.

They are rarely achieved with daylight. The sun being an exceedingly unreliable source, any calculations of daylight must be based on the light of the sky. For this purpose the daylight unit has been evolved, meaning the amount of light received on a horizontal surface from 1 per cent. of the hemisphere of the sky.

According to the changing brightness of the sky, the light of a daylight unit varies from zero to about 20 foot-candles; 6 foot-candles is a safe average.

If natural lighting is to stand up in competition with artificial illumination, the unobstructed window surface must extend to about one-third of the floor surface: this would result in 15–25 foot-candles at the darkest point of the room.

It is often said that such large windows would be glaring. But glare is seldom, if ever, the result of excessive absolute brightness, but of excessive brightness contrast. The brightness of the sky seen through the window will be the same in all cases and the brightness at the window will also be the same, resulting in a brightness contrast not exceeding 1 : 10 in a room with a one-third window. This is generally considered as admissible in good lighting practice.

In a room with a one-seventh window, however, the contrast may be 1 : 30 and more, and the sky will be felt as glaring. This starts the vicious circle: curtains at the window against the glare, hence greater darkness, hence glare anew, hence more curtains, and so on, until rooms are more fit for moles than men.

Wrong distribution of brightness, not general lack of light, is also the trouble in the traditional stair well, with the glare of the window thrown right into the eyes of the people walking down.

Wherever possible, the best way to avoid glare is equalization of brightness on all surfaces of the visual perisphere. As light attracts the eye, the highest brightness should be in the focal point, and gradually fade outwards. Because the eye is more sensitive to light from below, it should decrease strongly towards the bottom, slightly towards top and sides.

In the ideal case the object itself is the source of light. This occurs in advertising signs, or when looking at a bright object merely for enjoyment, i.e., at a sunset or a decorative lighting. Where silhouette perception is sufficient, this ideal condition may also be realized in the industrial world, as in engraving on a translucent surface.

Normally, however, the object is darker than the source from which it receives its light, and therefore this source should be shielded from the eye. This is easily done in the case of local lighting, though it is still often forgotten. It is not possible in general lighting, where every point of the visual perisphere may become the object of vision. Therefore, directed local lighting is generally preferable.

Fluorescent walls, ceiling and floor are the only available source which by itself would achieve equal lightness of an entire room, but at present hardly a practicable solution. Daylight in an all-glass building approaches this condition with an overcast sky, but requires means to control direct sunlight. In large rooms evenly distributed fluorescent tubes prove satisfactory. Normally, however, the light of the source must be diffused by transmission or reflection.

Any matt white surface, whatever the material, will have a reflection factor of about 80 per cent. In a room with windows in one wall, white walls and ceiling will contribute almost half the illumination. With dark surfaces even an approximate equalization of brightness can be achieved only by multiplying the sources; such rooms need windows in two or more walls, and for a distribution of lighting fixtures throughout the room. Any change in the colour of the source may affect not only the colour, but also the brightness of coloured reflecting surfaces. White surfaces help to equal-

ize illumination not only in space, but also in time, contributing evenly to daylight and to night light.

Unlike charity, reflected light ends at home, but begins out of doors. Every object is a source of light, and is often brighter than the sky. Sunlit snow may be forty times as bright as a deep blue sky, and even in the shade a white wall is brighter than a clear sky. Light from sources opposite a window is thrown into the depth of the room, and light from below will be reflected and diffused by the ceiling. Therefore walls facing a window, and pavements of courts, terraces, and balconies are more valuable sources of light than the upper part of the sky, which lights mainly the part of the room next to the window. These surfaces should be kept bright, but not to an extent that may produce glare. Walls facing north may be white, but walls and especially pathways exposed to the sun should be of a yellow or buff colour; this will also help to correct the cold colour from the sky.

CHAPTER THREE

GLARE

THERE are many factors, some of them complicated, involved in good illumination. Because of this, lighting installations should be designed by a competent illuminating engineer. However, those who live with the lighting provided by experts and those who must justify its cost should be familiar with some of the factors to be considered. These can be summed up under the heading of *quality*, which includes glare, the colour of light, its direction and distribution, diffusion, etc., and *quantity*, or the amount of illumination.

It is not a particularly difficult problem to supply a factory with the amount of light specified in the table of Foot-Candle Intensities given in the Appendices. Reflectors are available which provide these values economically. There are many installations, however, where poor conditions for vision exist in spite of adequate foot-candle level. This is usually because precautions were not taken to provide illumination without glare.

Glare may be defined as brightness, within the field of vision, of such a character as to cause discomfort, annoyance, interference with vision, or eye fatigue.

When the eye is exposed to glare, the pupil contracts as a protective measure, and less light reaches the retina than when the same illumination is supplied without excessive brightness in the visual field. Glare also reduces the sensitivity of the retina.

Always a hindrance to vision, glare often, like smoke from a chimney, represents a positive waste of energy as well. It is one of the most common and serious faults of lighting installations.

Regulations now require the proper shading of lamps in factories to guard against glare.

Glare is objectionable because: first, when continued, it tends to injure the eye and to disturb the nervous system; secondly, it causes discomfort and fatigue, thus reducing the efficiency of the worker; and thirdly, it interferes with clear vision and thus reduces efficiency and, in many cases, increases the risk of accident or injury to the worker. From both a humani-

tarian and a business standpoint, the factory executive should banish glare, whether from natural or artificial sources.

There is need for a simple instrument for measuring glare. If this were available it would be, like the light meter, an invaluable help in educating users of light in the right direction by showing them unquestionable quantitative comparisons. There are so many factors entering the situation that an instrument capable of evaluating them all has not been found practicable. The result is that such glare data as can be given to a particular light-source must be based upon the impression which it creates upon the eye itself. The eye has the capacity of estimating which of two light sources is he more glaring, taking into consideration both brightness and candle-power when the two sources are side by side and seen against the same background. This quality of the eye has been used as the basis for a relatively simple system of glare rating.

If a series of comparative standards are supplied using respectively 10, 15 and 25-watt lamps and also larger sizes, each placed in a 6-inch opal ball globe, then a light-source can be judged as to comparative glare by placing these standard globes beside it one by one and finding which appears to be equally glaring. For example, it may be found that a 16-inch semi-indirect lighting unit containing a 300-watt lamp appears to the eye just about equal from the glare standpoint to a 50-watt lamp in the 6-inch opal ball globe. The 300-watt unit would then be classified arbitrarily as Grade E in the following table of classification.

Grade	
A	10-watt tungsten filament lamp in a 6-inch opal ball globe.
B	15 ,, ,, ,, ,, ,, ,, ,,
C	25 ,, ,, ,, ,, ,, ,, ,,
D	40 ,, ,, ,, ,, ,, ,, ,,
E	50 ,, ,, ,, ,, ,, ,, ,,
F	60 ,, ,, ,, ,, ,, ,, ,,
G	100 ,, ,, ,, ,, ,, ,, ,,
H	150 ,, ,, ,, ,, ,, ,, ,,
I	300-watt opal lamp
J	500 ,, ,, ,,
K	1000 ,, ,, ,,

It will be noted that Grade K is representative of light sources which are extremely bright and glaring, whereas Grade A can be placed almost anywhere in the field of view without causing discomfort.

Where lamps are placed at considerable heights above the eye level, relatively bright light sources can be tolerated, and this is particularly true in positions such as out-of-doors at night where little close discrimination of detail is required of the eye.

On the other hand, where light sources are hung low and are constantly in the field of vision of a worker seated at a table or work-bench, then the light source should be of Grade A or B, that is, very soft and free from

glare. Again, the effect of glare is cumulative, therefore in a long room where a considerable number of light sources are in one's field of vision it is necessary to have better diffused sources than in a room of limited area where only one or two units are visible to a worker.

Here are some grades of light source which should not be exceeded for good conditions of vision. Where interior backgrounds are very dark in tone, a light source one grade softer than indicated is recommended.

Height of Light Source above floor in feet.	Factory Roads and Yards.	Storage Warehouses.	Ordinary manufacturing operations.	Mfg. Offices and operations where workers are seated facing in one direction for long periods.
6·5 or less .	—	D	C	A
6·5 to 7·5 .	—	D	C	A
7·5 to 9 .	F	E	D	C
9 to 11 .	G	G	E	D
11 to 13 .	H	G	G	E
13 to 16 .	H	H	H	F
16 to 20 .	I	I	I	G
20 and over .	J	J	J	H

Several of the more common industrial light sources have been rated for glare and the results classified and tabulated below. The standpoint of glare has been derived from the classifications given on page 12.

Natural Light Sources (as seen through windows)	Grade
Sun	K
Bright southern sky	G
Dull or northern sky	C
Sun shining on prism glass	J
Mercury vapour lamps	G
Carbon incandescent lamps, 16 candle-power . . .	F
" " " 32 " "	G

Tungsten Filament Lamps.	40 watts	60 watts	100 watts	150–200 watts	300 watts	500–1000 watts
Bare lamps	G	H	I	J	J	K
Pearl lamps or pearl globes*.	D	F	G	H	I	J–K
8-inch opal globes . .	C	E	F	—	—	—
12-inch opal globes . .	—	—	E	G	H	I
16-inch opal globes . .	—	—	—	F	G	H
Flat reflectors—filament position visible . . .	G	H	I	J	J	K
Dome reflectors—steel or dense glass : Filament position visible from working position	G	H	I	J	J	K
Filament position not visible	B	B	D	D	E	G
Dome reflectors—white bowl lamps	—	—	—	F	G	
Bowl reflectors—steel or dense glass : filament position visible . . .	G	H	I	J	J	K
Filament position not visible .	C	C	D	E	G	H
Totally indirect lighting* .	—	—	B	B–C	C	D
Semi-indirect bowl* . .	—	—	B–D	C–D	C–E	D–G

* Where a range of classifications is given, the best grade, that is the lowest, applies to bowls that are of dense glass, and the poorest to bowls which have a decidedly bright spot in the centre.

There are six principal factors affecting glare and the main causes are outlined below. First is Brightness of Source. The light source may be too bright, that is, it may have too high a candle-power per square inch of area.

A glance at the sun proves that an extremely bright light source within the field of vision is capable of producing acute discomfort. Light sources of far lower brightness than the sun, as for example the filament of an incandescent electric lamp or the incandescent mantle of a gas lamp, may also cause discomfort, although the annoying effect is not quite so marked.

Supplementary lighting sources should be carefully designed so that the light is confined to the immediate working area. If this precaution is not observed, supplementary lighting devices are likely to be extremely annoying, not only to the workman who is using such a source, but more particularly to others in the vicinity.

The second great cause of glare is Total Volume of Light. The light source may be too powerful for comfort ; that is, it may have too great a total candle-power in the direction of the eye.

Too frequently glare is assumed to be entirely a question of the bright-

glare. Again, the effect of glare is cumulative, therefore in a long room where a considerable number of light sources are in one's field of vision it is necessary to have better diffused sources than in a room of limited area where only one or two units are visible to a worker.

Here are some grades of light source which should not be exceeded for good conditions of vision. Where interior backgrounds are very dark in tone, a light source one grade softer than indicated is recommended.

Height of Light Source above floor in feet.	Factory Roads and Yards.	Storage Warehouses.	Ordinary manufacturing operations.	Mfg. Offices and operations where workers are seated facing in one direction for long periods.
6·5 or less .	—	D	C	A
6·5 to 7·5 .	—	D	C	A
7·5 to 9 .	F	E	D	C
9 to 11 .	G	G	E	D
11 to 13 .	H	G	G	E
13 to 16 .	H	H	H	F
16 to 20 .	I	I	I	G
20 and over .	J	J	J	H

Several of the more common industrial light sources have been rated for glare and the results classified and tabulated below. The standpoint of glare has been derived from the classifications given on page 12.

Natural Light Sources (as seen through windows)	*Grade*
Sun	K
Bright southern sky	G
Dull or northern sky	C
Sun shining on prism glass	J
Mercury vapour lamps	G
Carbon incandescent lamps, 16 candle-power . . .	F
" " " 32 " "	G

Tungsten Filament Lamps.	40 watts	60 watts	100 watts	150–200 watts	300 watts	500–1000 watts
Bare lamps . . .	G	H	I	J	J	K
Pearl lamps or pearl globes*.	D	F	G	H	I	J–K
8-inch opal globes . .	C	E	F	—	—	—
12-inch opal globes . .	—	—	E	G	H	I
16-inch opal globes . .	—	—	—	F	G	H
Flat reflectors—filament position visible . . .	G	H	I	J	J	K
Dome reflectors—steel or dense glass : Filament position visible from working position	G	H	I	J	J	K
Filament position not visible	B	B	D	D	E	G
Dome reflectors—white bowl lamps	—	—	—	F	G	
Bowl reflectors—steel or dense glass : filament position visible . . .	G	H	I	J	J	K
Filament position not visible .	C	C	D	E	G	H
Totally indirect lighting* .	—	—	B	B–C	C	D
Semi-indirect bowl* . .	—	—	B–D	C–D	C–E	D–G

* Where a range of classifications is given, the best grade, that is the lowest, applies to bowls that are of dense glass, and the poorest to bowls which have a decidedly bright spot in the centre.

There are six principal factors affecting glare and the main causes are outlined below. First is Brightness of Source. The light source may be too bright, that is, it may have too high a candle-power per square inch of area.

A glance at the sun proves that an extremely bright light source within the field of vision is capable of producing acute discomfort. Light sources of far lower brightness than the sun, as for example the filament of an incandescent electric lamp or the incandescent mantle of a gas lamp, may also cause discomfort, although the annoying effect is not quite so marked.

Supplementary lighting sources should be carefully designed so that the light is confined to the immediate working area. If this precaution is not observed, supplementary lighting devices are likely to be extremely annoying, not only to the workman who is using such a source, but more particularly to others in the vicinity.

The second great cause of glare is Total Volume of Light. The light source may be too powerful for comfort ; that is, it may have too great a total candle-power in the direction of the eye.

Too frequently glare is assumed to be entirely a question of the bright-

ness of the light source; of equal importance is the question of total candle-power. Experience has shown that a 500-watt lamp in a 10-inch opal globe or a mercury-vapour lamp of an equivalent light output, hung seven or eight feet above the floor and a similar distance in front of the observer, will prove quite as glaring as the exposed filament of a 50-watt incandescent lamp in the same position. The brightness of the opal globe unit is only a few times that of a candle flame, but its total candle-power and consequently the quantity of light which reaches the eye is altogether too great, so that its effect is worse than that of the bare filament of lower candle-power, although the latter may have a brightness as high as 3,000 candles per square inch. An unshaded window often causes glare, due, of course, to the large volume of light rather than to the high brightness of the sky.

The third cause of glare is Wrong Position in the Field of View. A given light source may be placed at too short a distance from the eye or it may be too near the centre of the field of vision for comfort; that is, within too small an angle from the ordinary line of sight.

The 500-watt opal globe unit mentioned earlier in this chapter would seldom cause discomfort if placed, say, eighty feet away from the observer, for at this distance the total quantity of light entering the eye would only be one-hundredth of that received at eight feet. Again, the same light source would probably be found quite unobjectionable at a distance of eight feet from the eye provided this distance were obtained by placing the lamp four feet ahead of the observer and seven feet above the ordinary eye level. In this case the lamp would scarcely be within the ordinary field of view.

The natural position of the eye during intervals of rest from any kind of work is generally in the horizontal direction, and it is desirable that during such periods the worker should be freed from the annoyance caused by glare. Glare is the more objectionable the more nearly the light source approaches the direct line of sight. While at work the eye is usually directed either horizontally or at an angle below the horizontal.

Glaring objects at or below the horizontal should especially be prohibited. The best way to remove light sources out of the direct line of vision is to place them well up towards the ceiling. Local lamps, that is lamps placed close to the work, if used must be particularly well screened.

Contrast with Background is the fourth reason of glare. The contrast may be too great between the light source and its darker surroundings.

It is a common experience that a lamp viewed against a dark wall is far more trying to the eyes than when its surroundings appear relatively light. In order to provide a light background—usually ceiling or walls—which will minimize contrasts, the surfaces should be painted a light colour and the method of illumination employed should be such as to direct some of the light upon the background. In many cases the ceiling appears almost black under artificial light simply because no light reaches it.

With daylight, on the other hand, the walls of a room are often so well illuminated that they appear brighter than the work itself, and this also is a condition which is not conducive to good vision. In general, a light tone for ceilings and high side walls and a paint of medium reflecting power for the lower side walls will usually be found most satisfactory under both artificial and natural lighting.

Where strictly local systems of lighting are employed—that is, where individual lamps are supplied for all benches and machines—and no overhead lighting is added, the resulting contrasts in illumination will usually be found so harsh as to be objectionable even though the lamps themselves are

well shielded. The eyes of the workman looking up from his brightly lighted machine or bench are not adapted for vision at low illuminations hence, if nearby objects and passages are only dimly lighted he will be compelled either to grope about, losing time and risking accident, or to wait until his eyes have become adapted to the low illumination.

Glancing back at his work, he again loses time while his eyes adjust themselves to the increased amount of light which reaches them. If long continued, this condition leads to fatigue as well as to interference with vision and to accidents. In other words, where local lamps are employed there should also be a system of overhead lighting which will provide enough illumination of all surrounding areas to avoid such undesirable contrasts.

Time of Exposure is a common form of glare. The time of exposure may be too great—that is, the eye may be subjected to the strain caused by a light source of given strength within the field of vision for too long a time.

Where a worker is seated and his field of vision is fixed for several hours at a time, light sources of lower brightness and lower candle-power are required than where the operator stands at his work and shifts his position and direction of view from time to time. In the first case the image of the light source is focused on one point of the retina for considerable periods of time and is obviously more likely to cause discomfort and eye-strain than when focused for short periods only. Those who are forced to work all day at benches facing a window are likely to suffer from this form of glare.

Glare by Reflection is brought about usually by the reflection of light from polished surfaces in the field of vision. The difficulty experienced in protecting the eyes from this kind of glare is sometimes very great. The brightness of the image on the working surface is, of course, proportional to the brightness of the light source above it, and hence, one way in which to minimize this effect is to diffuse the downward light; that is, to use an opal bowl or an enamelled bowl lamp, or an enclosing fixture, or to employ semi-indirect or totally indirect lighting fixtures.

In some cases the light source can be so placed that its reflection is directed away from, rather than towards, the eyes of the workers. The avoidance of highly polished surfaces in the line of vision is another good way to minimize reflected glare.

On the other hand, there are some instances where sharp shadows and specular reflection from the materials worked upon actually assist vision. For example, in sewing dark materials the thread is much more easily distinguished when illumination is secured from a concentrated light source, such as a brilliant lamp filament which casts sharp shadows and gives rise to a distinct glint from each thread. However, in these cases the light source must be particularly well shielded from the eyes of the worker.

For most visual tasks it appears that with equal foot-candles of illumination, variation in colour quality has little or no effect upon clearness and quickness of seeing. However, in certain industries colour discrimination is highly important and special light sources are necessary to provide lighting that will enable the matching to be carried on most accurately.

Light-coloured surfaces serve several purposes in the factory. They are of particular value in providing a high utilization of light by reflecting a large part of it towards the working areas. Also, bright window areas and artificial light sources are less uncomfortable to the eye when viewed against light backgrounds.

Dirty wall surfaces in British factories would undoubtedly cover several thousand acres. These dingy surfaces are all thirsty for light, soaking it up instead of allowing it to lighten the workers' job—both literally and figuratively.

A spectacular demonstration of the light-reflecting value of paint is in the white pavement and road markings which appeared in towns during war-time black-outs. Even the little light available in such circumstances is caught and reflected by these lines of white paint.

Better seeing conditions, and consequently increased safety, result from the application of correct colours in finishing industrial interiors. Ceilings and walls are as much a part of the lighting system as are the lamps and reflectors. These surfaces should yield a maximum diffusion of light without specular reflection or glare.

Colour is not a substitute for ventilation, but certain tints do give a feeling of coolness. In sections of the factory where temperatures are high, the cool colours—those without trace of red or yellow—may be used with advantage. Blues, greens and greys are said to inhibit 'warm' reflection.

White, of course, leads all colours in light reflection value. A good-quality flat white paint will reflect approximately 89 per cent. of the light. For that reason it is a favourite wherever good lighting is an important factor. However, there are times when the decorative scheme or the psychological element makes a tint advisable. Their reflection values are shown in the table printed on pages 76 and 77.

Many progressive concerns are painting all their machinery in light-tinted durable paints. This serves several purposes such as greater protection of machine surfaces, ease of cleaning (and of detecting dirt on the machine) and the increasing of the amount of light which is reflected to the otherwise shadowed sections of the machine.

A useful coating for almost any surface under a wide variety of conditions is aluminium paint. The aluminium pigment may be obtained in either powder or paste form to be mixed with a medium suitable for the conditions under which it is to be used. The medium is highly important, because a general purpose paint will not give the best service under some of the conditions encountered in industry.

The aluminium pigment consists of tiny flat flakes which protect the surface by leafing, protecting the surface from the damaging action of both sunlight and moisture. Because of its high degree of reflectiveness this paint is often used on walls and ceilings as well as on machinery. Its silver white colour reflects light in such a manner as closely to simulate daylight, making it a frequent choice for dye works and clothing factories.

One of the most important benefits obtained from maintaining a cheerful, pleasant workshop with light walls and ceilings and light-coloured machinery is the effect upon the spirit of the men who work there. Invariably such an interior greatly improves the morale of the workmen as compared with the dull, dark room.

CHAPTER FOUR

LIGHTING AND SAFETY

IN the eighteenth century artificial light was merely a weak competitor of darkness ; only a generation ago it became a competitor of daylight. To-day the position is reversed and natural light is a competitor of artificial illumination, asked to show reason why it should not be replaced by its younger brother.

It is no longer possible for the architect of industrial buildings to design for daylight only and let artificial light look after itself. If it is true that there cannot be too much light, it is equally true that it must be the right kind and in the right place.

In the absence of light man gropes fearfully, wondering at each move whether an accident will happen. The presence of light instinctively gives to him that sense of assurance so necessary for complete confidence in himself and his work.

Such is a very simplified statement of the relation between light and safety. However, light is needed for the amazingly complex function of seeing which is taken so much for granted. Consequently the quantity of light and quality of lighting (direction, diffusion, source, size and brightness) greatly affect our ability to see.

Everyone has been amused and mystified by the optical illusions which magicians use. Of first importance is the fact that conventional factory lighting in many places provides the same visual illusions. When the eye is sufficiently fooled or fatigued by the effort of seeing, an accident is the logical result.

Both materially and psychologically, illumination affects the well-being of every industrial establishment. Considering that more than four out of five of all mental impressions are received through the eyes, this is quite understandable. The benefits of good natural and artificial industrial illumination plus bright and cheerful surroundings have been established in tests covering many years, and include the following :

1. Reduction of accidents.
2. Greater accuracy of workmanship, resulting in an improved quality of product with less spoilage.
3. Increased production and decreased costs.
4. Less eye-strain.
5. Improved morale among workers, resulting in a decrease in labour turnover.
6. Greater cleanliness.
7. More easily maintained order and neatness in the factory.
8. Supervision of employees made easier.

Statistics regarding the number of accidents in factories each year are available in tables published with the Annual Reports of H.M. Chief Inspector of Factories. They are worthy of detailed study. The number of fatalities in Great Britain arising out of or in the course of gainful employment in 1941 was 1,646. Also during the same period the reportable non-fatal accidents involving not less than three days' absence from normal employment reached the staggering total of 269,652.

This includes accidents at docks, warehouses, building operations, and so on.

There is reason to know that defective vision and deficient or unsatisfactory lighting installations are responsible or contributing factors in about 20 per cent. of these accidents. A reasonable estimate will show that from these causes industry was deprived of the equivalent services of about 8,000 workers throughout 1941 due to the lost-time non-fatal accidents. This is indeed a high price to pay for the neglect of light and vision.

That this condition could exist year after year is all the more surprising because of the fact that the remedy was so easily applied by the Minister of Labour and National Service by prescribing a standard of lighting for certain factories in Statutory Rules and Orders 1941, No. 94. These regulations have already shown beneficial results in many ways other than the safety involved. Accidents caused by carelessness, inattention, or ignorance can be eliminated only by long-continued painstaking propaganda aimed to change long-established habits.

On the other hand, elimination of accidents due to inadequate or improper lighting is simply a matter of buying the proper equipment, installing and operating it under competent direction. It seems logical enough to include adequate illumination in the list of safeguards, because it points out the dangers and helps in avoiding them just as effectively as a fence points out the danger of a revolving flywheel.

Safety engineering in industry consists of mutually adapting the workman and his environment so that he can work without injury to himself or to others. Notable advances have been made in recent years in analysing accident causes and perfecting safety devices for the worker's protection. Educational work is implanting a sense of responsibility in the individual workman. These developments have been outstanding contributions towards greater safety, but *seeing* as a human activity and as an almost universal factor in the safe operation of machinery has received comparatively little attention.

The safety officer's job consists essentially in preparing a safe environment for the workers. If this were *perfectly* done, none of the occurrences which are termed accidents could possibly happen. The environment should be designed to compensate for the limitations of human capability.

On the other hand, the workman must understand his personal responsibilities regarding acts which might conceivably cause injury to himself and to others. The admirable work done by the Royal Society for the Prevention of Accidents is successfully implanting this sense of responsibility in the individual workman.

However, that this is but one phase of the safety problem is revealed by an analysis of accidents and their causes. Nearly all accidents involve a combination of personal and mechanical causes. The chain of circumstances or series of causes which have brought a workman to the verge of an injury can frequently be broken only if the workman can quickly and accurately see what is happening and act to prevent it.

Since an overwhelming majority of mental impressions are received through the eyes, any factor which helps that sense will increase the probability that the man will detect the causes of an accident and act to avert it. It is realized that with rapidly moving material, mechanical failure often results in an accident occurring too rapidly for any reaction on the part of the workman.

However, mechanical failures of this nature are usually preceded by

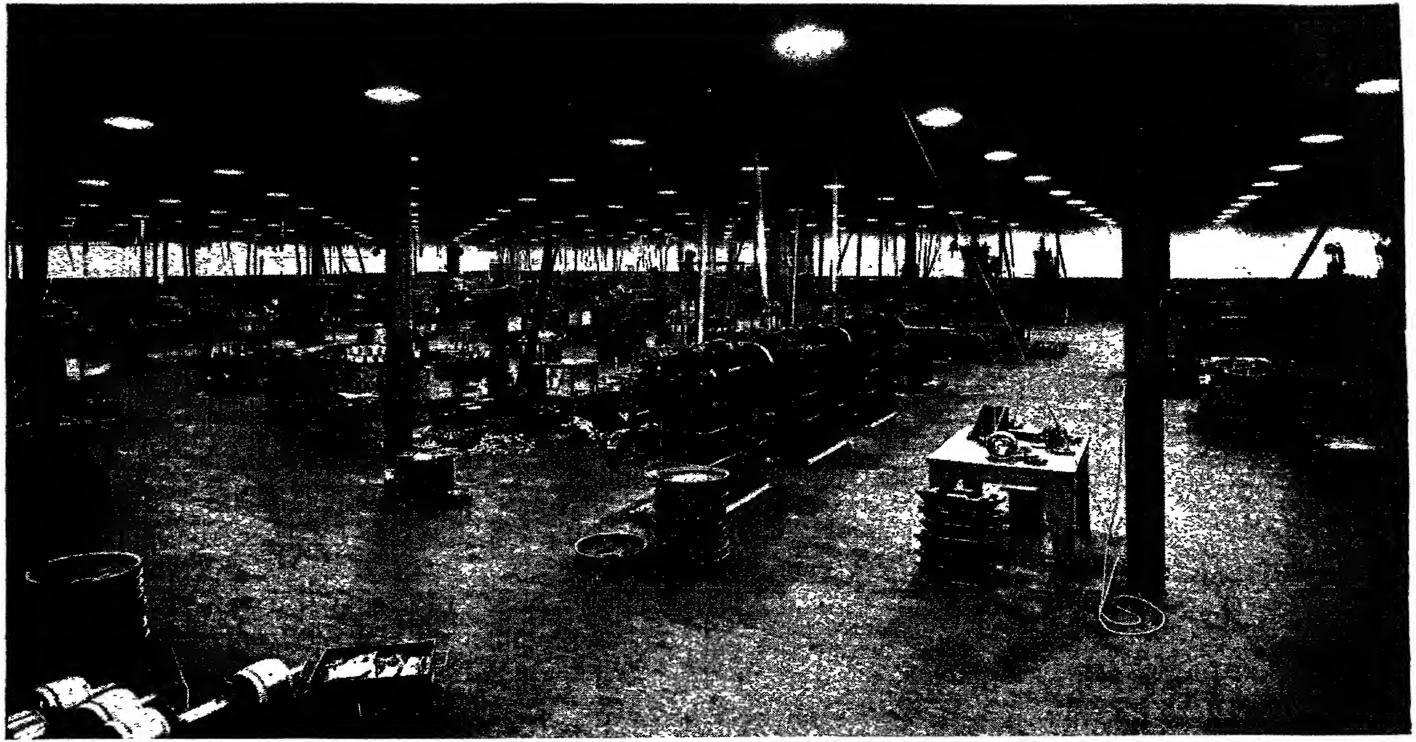
Here a test is being made of the illumination on a bar close to where the tool is cutting the metal. Note that the examiner is standing in a position similar to the operative looking at the work

For some operations the tool will be working on the face of a part parallel with the chuck face, so the vertical illumination here should also be tested

THE LIGHT METER

AN OFFICE

Well-dispersed, good general lighting was required with special attention given to light on the desks and the avoidance of shadows and shine on papers. A light ceiling makes the room more cheerful. Glassteel diffuser reflectors with 300-watt lamps were used.



A MACHINE SHOP

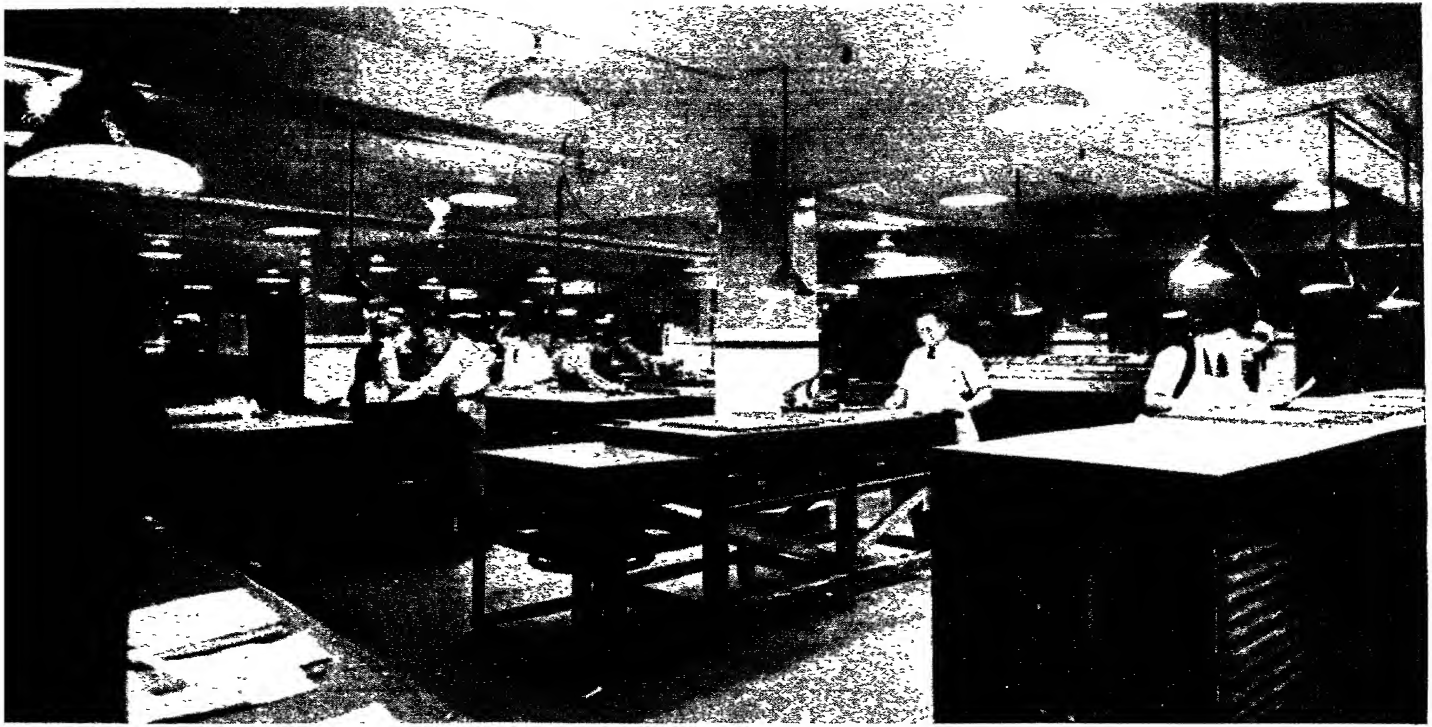
Good general illumination was required with particular attention given to the light on machines, lathes, drills, etc. Glare has been avoided and all moving parts are well lit. R.L.M. reflectors with 150-watt lamps were used

LEATHER SOLES STORE AT A BOOT AND SHOE FACTORY

Requirements vary with the layout of individual stores and the material concerned. A good light down the gangways and into the bins is needed. Vertical elliptical reflectors with 60-watt lamps were used here

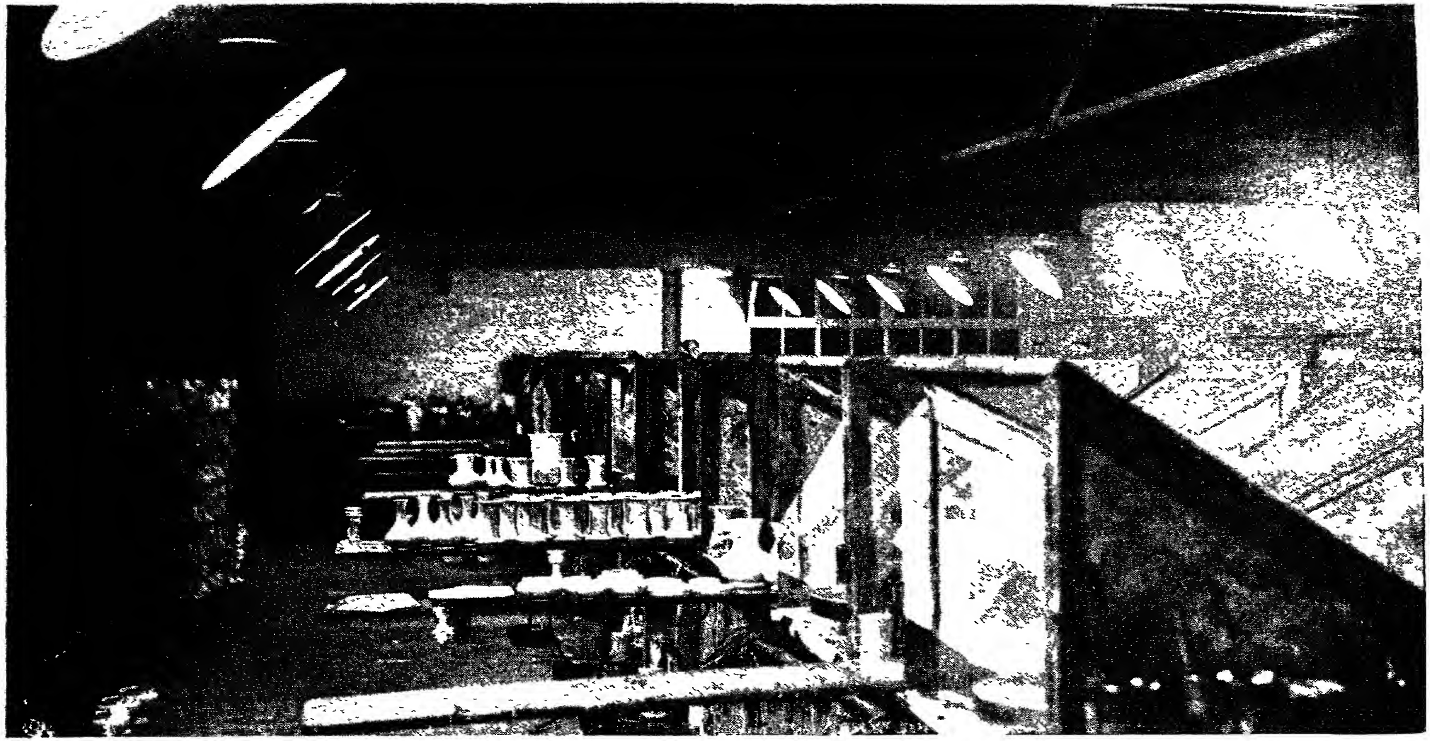
PRESS SHOP AT A CYCLE FACTORY

Good general lighting was needed with special care to ensure adequate light on the machines where the work is handled. R.L.M. reflectors were used



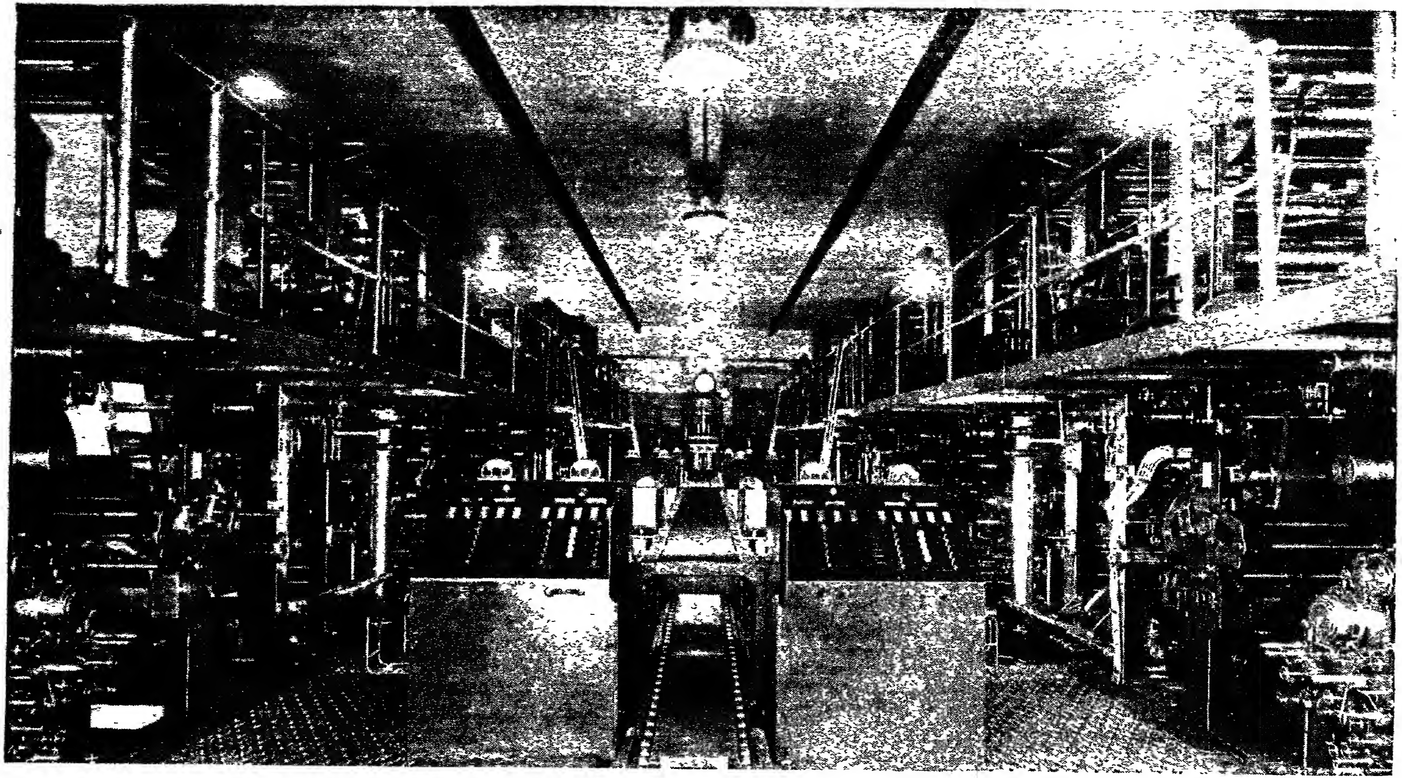
COMPOSING ROOM OF A NATIONAL NEWSPAPER

Good general lighting was required, especially over the cases and benches, with the avoidance of glare and danger of shine by reflected glare. For the general lighting glassteel diffuser reflectors were used and the supplementary lights over benches were fitted with vertical elliptical reflectors



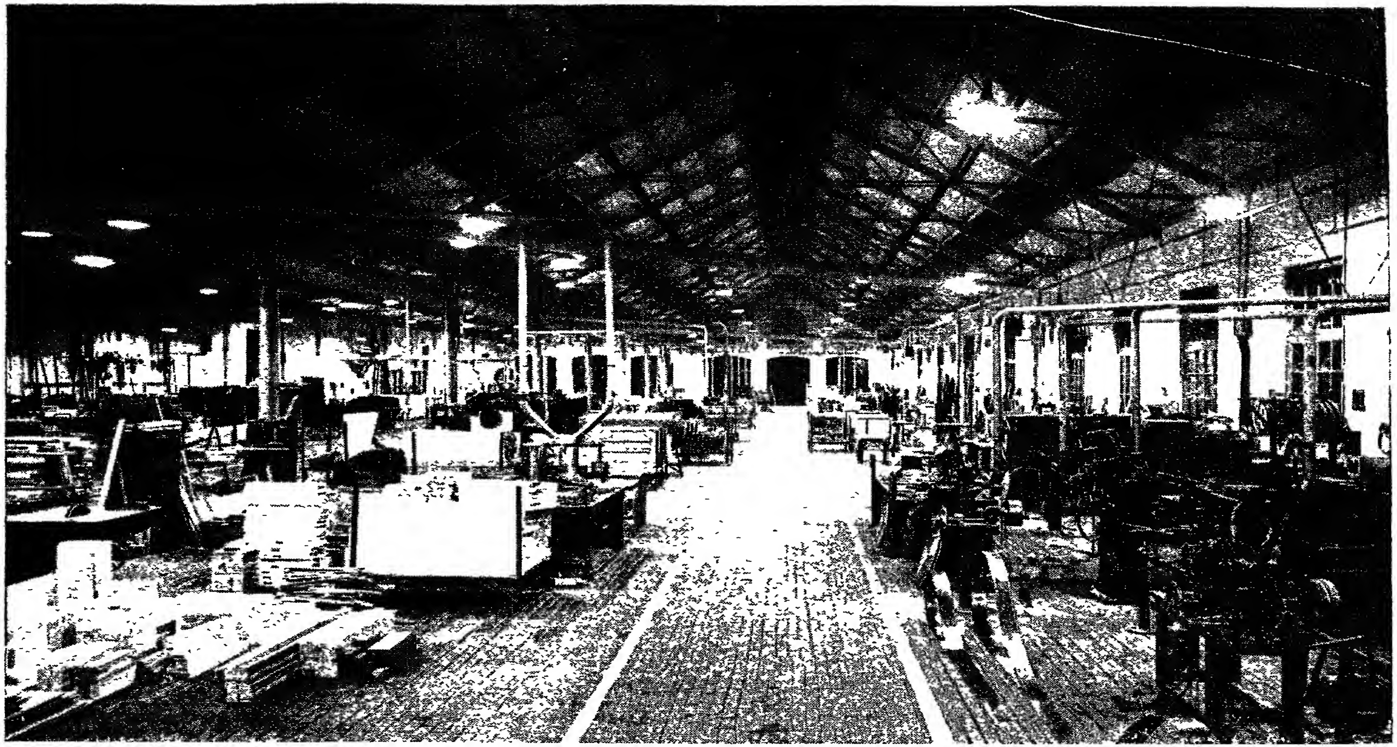
A POTTERY SPRAYING DEPARTMENT

Good light in the booths with no shadows from the operators was needed. Porcelain well glass parabolic angle fittings with 75-watt lamps were used



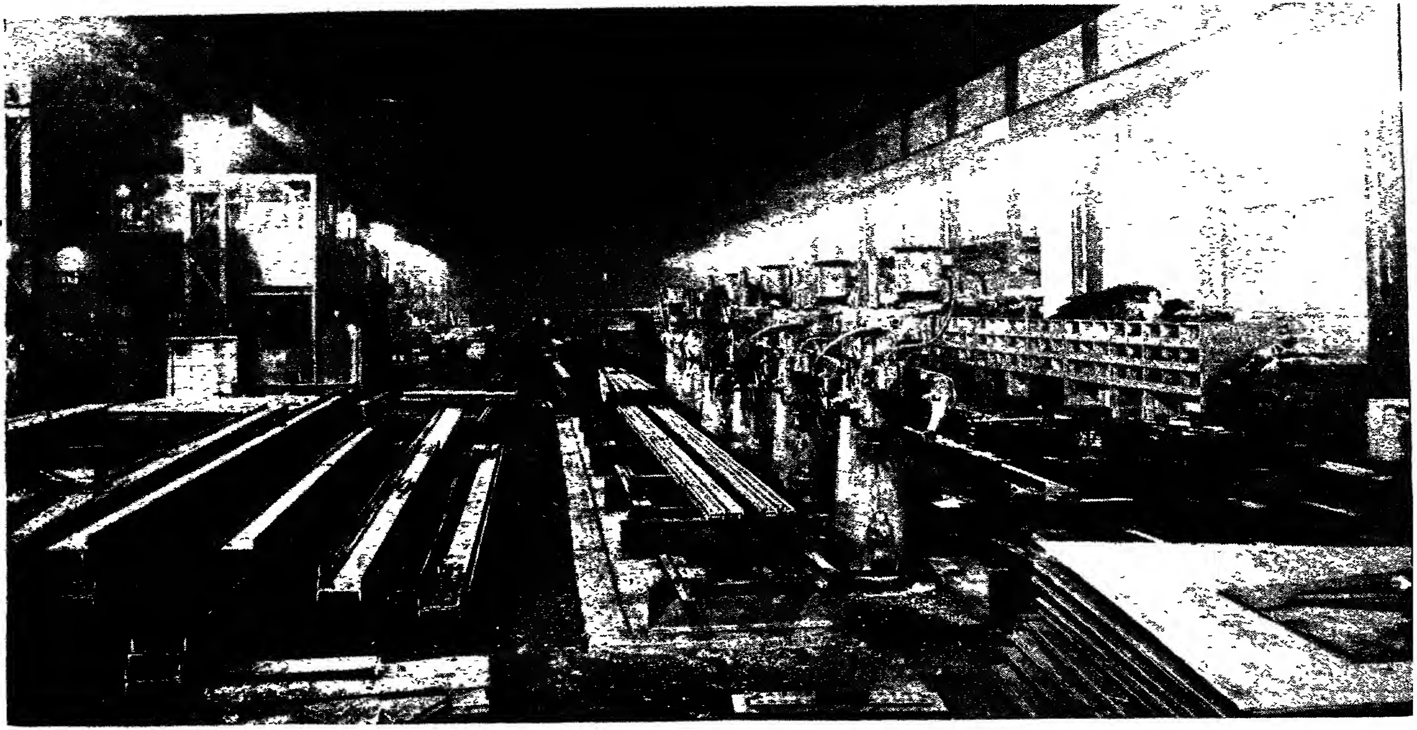
A NEWSPAPER PRESS ROOM

Good glareless illumination was needed, particularly at the printing points and at the delivery. Owing to the large mass of machinery care was needed to ensure the light reaching beneath the upper part. Glassteel diffuser reflectors with 500-watt lamps and Benjflux reflectors with 150-watt lamps were used.



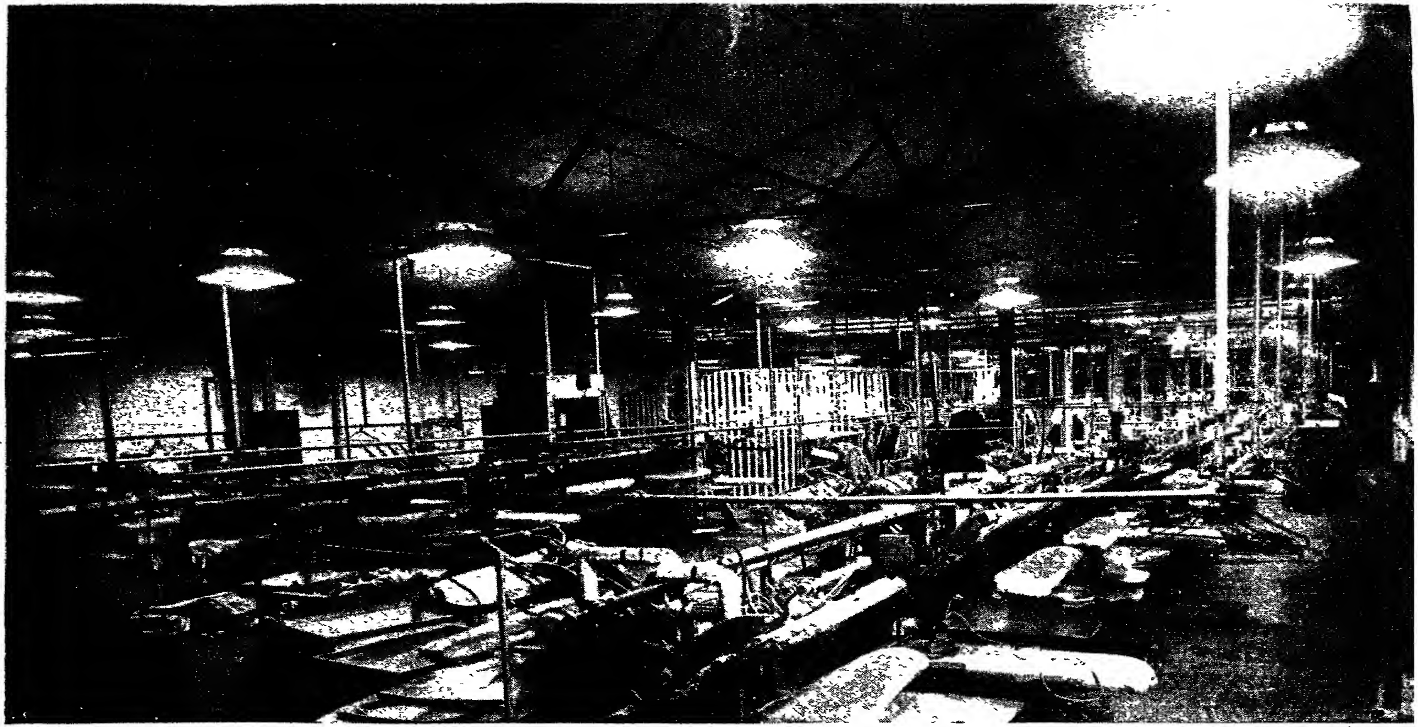
WOODWORKING DEPARTMENT OF A RAILWAY CARRIAGE SHOP

Good general illumination with absence of shadows enabling material to be handled easily and special attention to the lighting on machines and all moving parts was required. R.L.M. reflectors with visor glass fronts were used



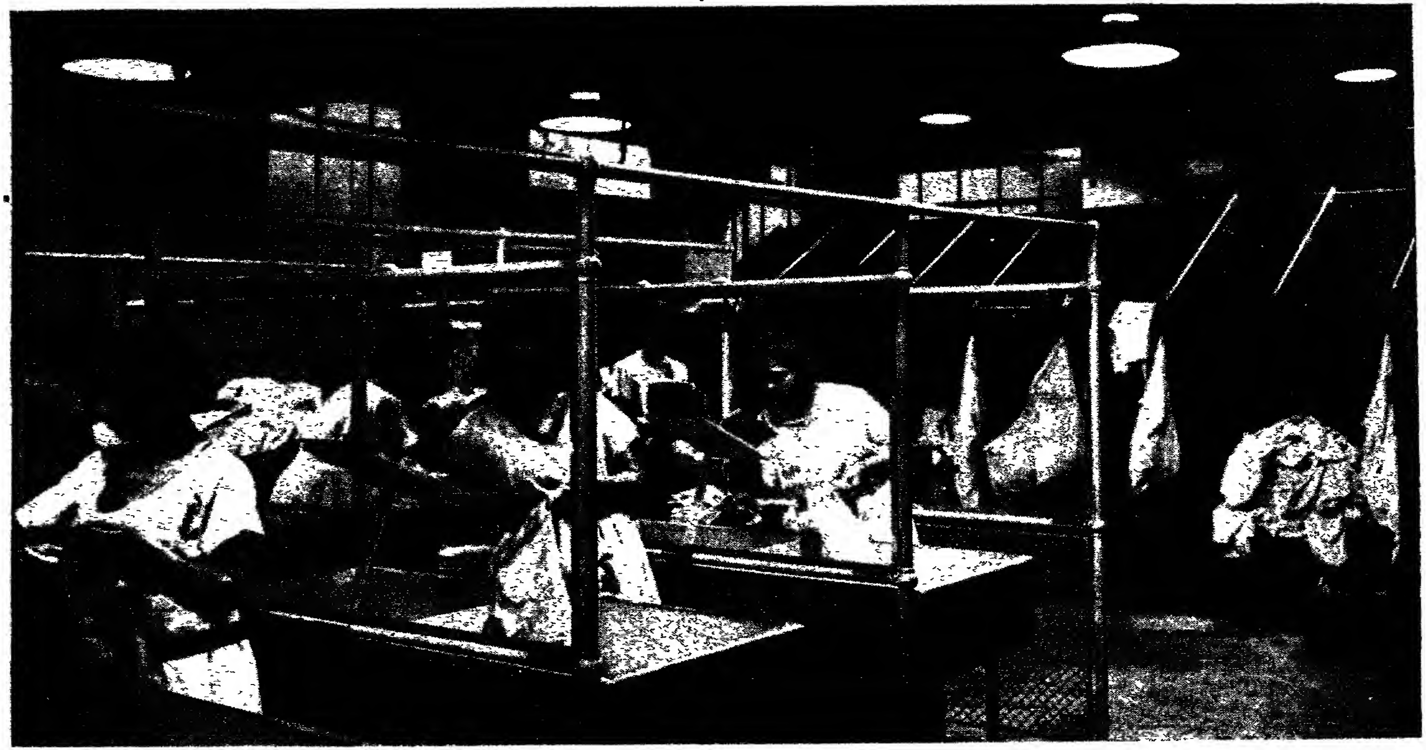
AN ENGINEER'S HEAVY ENGINEERING DEPARTMENT

The large structures erected in these works combined with big overhead cranes, sometimes make lighting difficult. Well-diffused light was required, combined with absence of shadows. This means that light must reach underneath structures. The method used depends upon the site. Floodlights with 300-watt lamps down each side of the bay were used



CLEANING AND PRESSING AT A DYE WORKS

A good light was required to see the dark fabrics clearly and this needed to be well-diffused to avoid shadow and to reach under the presses. Benjamin glassteel diffusers with 300-watt lamps spaced 10 feet apart to give an average of 23 foot-candles were used

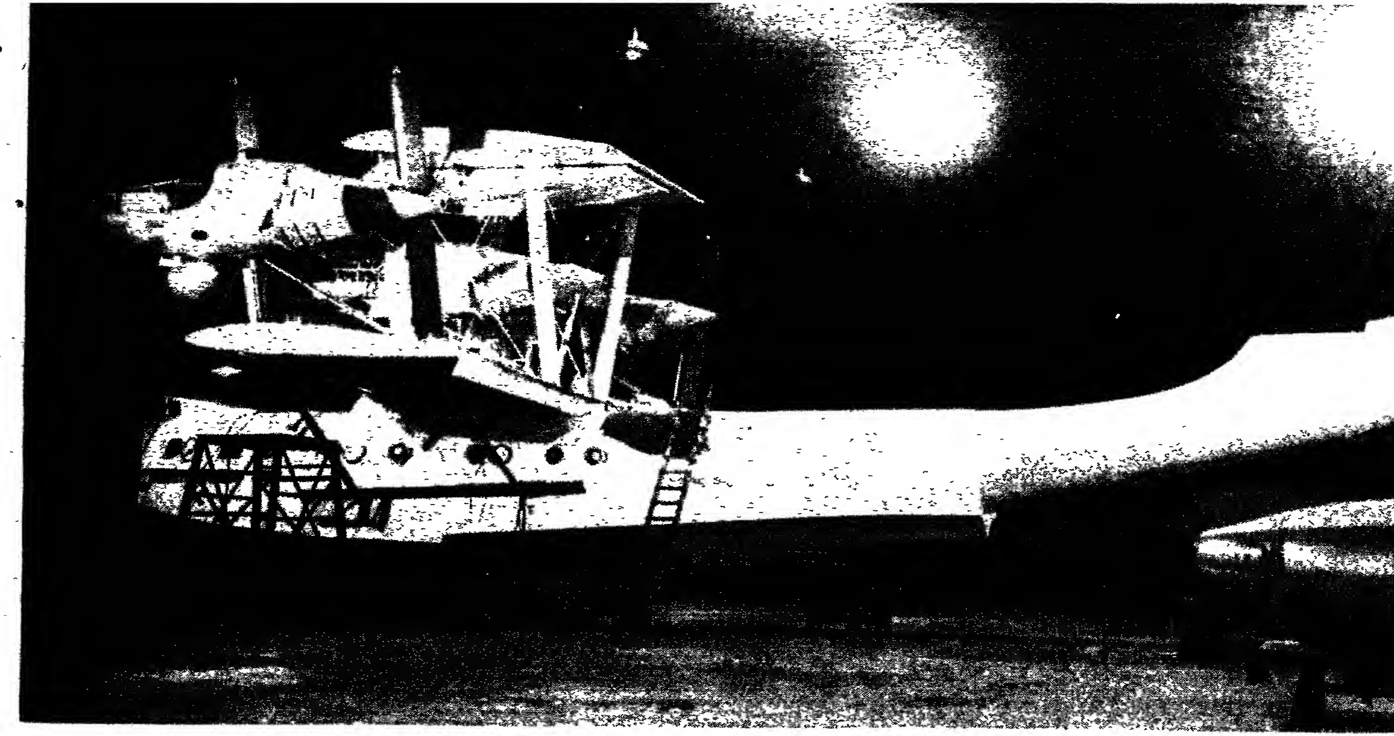


SORTING AND MARKING AT A LAUNDRY

Good, well diffused lighting was necessary to distinguish the marking and glare must be avoided. Benjamin glassteel diffusers were used

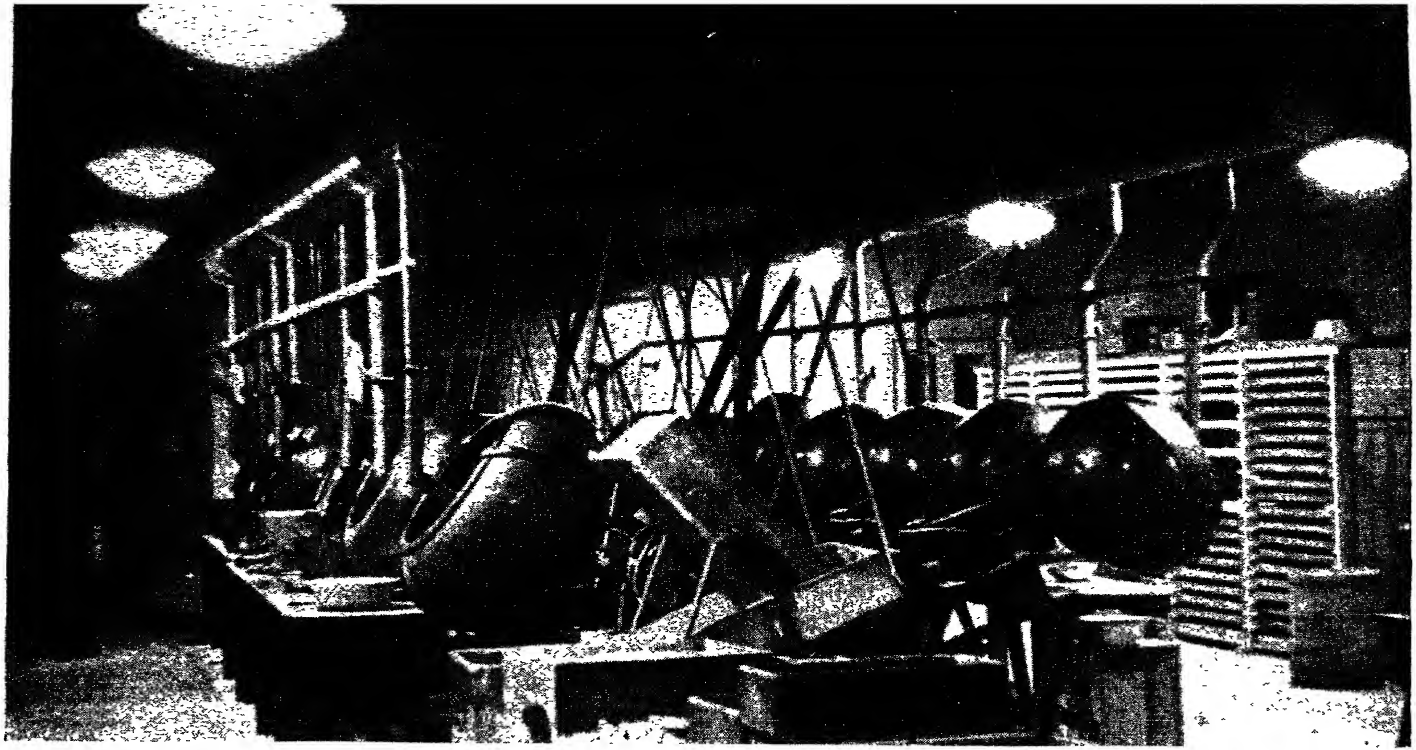
AN ENGINEER'S DRAWING OFFICE

Well dispersed lighting of good intensity was required on both horizontal and vertical surfaces arranged to avoid shine on the paper and of course no glare or shadows at the pencil point. Benjamin design "C" Bencolites with 300-watt lamps were used



AIRCRAFT ASSEMBLY WORKS

Here it was necessary to distribute the light well and for it to penetrate underneath the various parts of the aeroplane as it is built up. Side lighting combined with top lighting was required. These requirements have been secured by using R.L.M. reflectors overhead and Benjamin duoflex reflectors on the sides of the bay all equipped with 1,500-watt lamps



A CHEMICAL WORKS

Well diffused lighting with particular attention to the machines was needed here. R.L.M. reflectors with visor glass fronts were used

AN ENGINEER'S FOUNDRY

Even lighting of modern intensity has been secured by using R.L.M. reflectors with visor glass fronts to protect against dirt and dust. 455 fittings with 150-watt lamps and 120 with 200-watt lamps were used

evidences of the existence of undue stresses or strains which may be detected by an alert man if sufficient illumination is provided.

In this connection, the close co-relation between the accident rate and illumination is not generally understood. In most cases where accidents are attributed to poor illumination they happen because there is improper quality or very little illumination at all. Poor or indifferent lighting as a contributing cause of accidents has been overlooked by most people.

Many factors of poor illumination, such as glare, both direct from the lighting unit and reflected from the work, or dark shadows, hamper seeing and will cause after-image and excessive visual fatigue which are an important contributing cause of industrial accidents. Many accidents which are attributed to an individual's carelessness can actually be traced to difficulty of *seeing*.

One great loss to industry is brought about by minor accidents. Employees may or may not report for first aid, but in either case they continue to work, and the quantity and quality of their work suffers. Such accidents are uncompensated for by insurance. Good lighting is a good way to guard against these costly minor accidents. The condition of the illumination at the point of accident should always be reported in accident investigations.

It is generally recognized that the individual workman is, in most cases, the final arbiter of his own safety. 'A careful workman is the best safety device.' Yet how much do we consider his ability to recognize his situation accurately and quickly? Psychologists estimate that more than 85 per cent. of all mental impressions are received through the eye. Therefore, this essential sense through which so much of our awareness of environment—the surroundings, work surfaces, tools, etc.—must pass should be helped in every possible way.

In employing a man, industry is really obtaining the sources of a body, a mind, any skill in using these which he has developed through training and experience, and the five senses through which the man co-ordinates his activity with the remainder of the organization. Of these attributes the body, the mind, the skill and the senses of hearing, taste, touch and smell are the responsibility of the employee. Whether they are useful or useless to him and his employer depends entirely upon himself. However, the sense of sight, which has been shown to be all-important, is dependent not only upon him, through the selection of eye-glasses when necessary and other care of the eyes, but also upon his employers.

For *sight*, alone of all the senses, is affected by an external agent, *light*, to an extent not yet fully known. And light, through the sense of sight, affects every activity of the workman, his powers of production, accuracy of workmanship, mental attitude and physical welfare.

Probably of greatest importance to the industrial safety officer, it minimizes and retards the development of fatigue. Good light is the one factor of environment which is fundamental to the efficient operation of the factory personnel. Yet it is not given the importance it deserves or will obtain when a fuller understanding of its value is realized.

Seeing is a day-long, week-in, week-out activity. In common with most other human behaviour which psychologists have studied, short period tests often indicate compensation or over-compensation by the subject. In other words, over relatively short periods a man can maintain a given rate of work under poor seeing conditions without apparent detriment. This is, however, done at the expense of his nervous and visual strength which eventually reduces his usefulness due to fatigue or impaired

seeing ability. Under such conditions he can be accurately described as accident prone. Also, if an accident should occur, it is seldom recognized that poor lighting was a contributing factor.

Everyone has observed men who faced windows ten or twelve feet away while engaged in intricate machine or bench operations. Window brightness may range from 100- to 1,000-foot candles, while it is rare that the brightnesses of the working surfaces are more than 10- to 50-foot candles—and they are often much less.

These working conditions are extremely fatiguing to the eyes, yet they have seldom been considered contributory to an accident. Such accidents are frequently attributed to negligence or carelessness of the worker, while actually a factor of environment, poor lighting, may be largely responsible.

For this reason it is obvious that reports of accident causes, even the more carefully planned ones, do not present a complete picture of the relation between light and accidents. As a matter of fact, detailed analysis of the accidents in which poor light is considered as a contributing cause seems always clearly to indicate that this cause is given only for a *lack* of light, and therefore does not include the great majority of cases where poor lighting may have affected the man's judgment by visual or nervous fatigue.

Seeing is to a great extent dependent upon external lighting conditions. It is necessary to consider not only the visibility of the object of regard but also the brightness and brightness ratios found in the entire visual field.

The visibility of any object is determined by four factors :

1. Size of the object or details to be seen.
2. Contrast of the object with its background.
3. Brightness of the object.
4. The time it takes to see.

These factors are so interlocked that for any particular visual task if any three of them are established, the fourth is determined by the other three. Within our work world to-day both the size of the object and its contrast with the background are usually determined by the character of the work. Brightness and time are inversely variable since eyes require a definite time interval to see, just as a camera requires a definite exposure time to obtain a picture.

It is possible to carry the analogy further since eyes see more quickly with higher illumination than with low, just as a camera requires a shorter exposure time under the midday sun than at dusk. If a wheel rotating at constant speed is seen with good illumination, one obtains an impression in a very short time, during which the wheel has not moved appreciably. By a quick series of impressions we have the knowledge that the wheel is rotating at a relatively slow rate. However, if the illumination is suddenly decreased to a low level, but one frequently found in factories, the wheel is apparently moving much faster.

You might consider that a camera under the same condition would require a longer exposure time, during which the wheel would have moved appreciably and blurred the negative. The eye goes through the same process, and thus we get a blurred impression—one which takes longer to obtain and in which there is a longer time interval between impressions. Consequently the wheel appears to be moving considerably faster under poor illumination.

In this connection consider the very large proportion of accidents which are attributed not to a single material cause or act, but rather which are

be considered the result of a chain of events which culminates in the accident. If foreseen and acted upon quickly enough the accident could possibly have been averted. A split-second increase in the speed of vision may mean a margin of safety. For this reason, also, the ability to see quickly and accurately is a definite factor in any safety programme.

Very frequently the employee who is in his fifties and over is fitted physically and mentally for the responsible work for which his years of experience have prepared him. In many instances, however, failing vision will prevent such a worker from carrying on exacting work and thus cause him to be relegated to simple routine tasks in which his experience is of little value.

It has long been generally known that with increasing age the eyes lose their capacity for adapting themselves to the various demands made upon them. Focusing power decreases so materially that at around the age of forty-five it is frequently desirable to wear bifocal glasses which permit the eye to focus upon near objects and far objects with little change in the accommodation of the eye itself. The pupil of the eye gradually becomes smaller and its ability to change rapidly in size to compensate for various illuminations is decreased. The actual retinal sensitivity is also decreased with age.

These phenomena result in a considerably decreased ability to see. However, a rather carefully controlled production test proved that for an equal increase in foot-candles, a group of men with defective vision improved their working time 40 per cent. more than did another group with normal vision. In other words, better lighting helps those handicapped visually. These are most frequently the truly valuable skilled older workers, who can continue to carry on efficiently if the simple expedient is adopted of assisting their eyes with good illumination.

It should not be thought that good lighting is of assistance only to the older workers. It is true it benefits them in greater proportion than it does the younger employees. It also helps *all* the visually handicapped to a greater extent than those with perfect vision, but even those in the latter group find, under good lighting, a noticeable improvement in eye comfort which results in decreased fatigue.

In addition to poor visibility of the job in hand, another frequent environmental condition is glare. In so many factories the first thing that one sees is either bare, unshielded lamps or lamps inadequately shielded with small half-shades placed a few inches from the point of work. In many cases the men are conscious of this glare and turn the half-shades away from them or even paint the lamps, but in either case the lamp is exposed to the man facing him, with the same detrimental results. This is unnecessary as there are supplementary lighting units on the market to-day which eliminate this difficulty.

A much less obvious type of glare is that caused by a metallic surface of reflection of excessively bright light sources. Consider, for example, the appearance of a micrometer when lighted by an ordinary lighting system in common use. Note that the detail of the scale is completely obscured by the bright streak on either side of it. For metallic surfaces of this sort it is necessary to have the reflection of a uniformly bright light source over a considerable portion of the surface.

Notice the great improvement when the micrometer is reflecting a large light source. Here there is no glare since the entire surface is uniformly bright and affords a background to the cut detail of the scale, which is

similar in appearance to a well-printed page. Accurate visibility measurements have indicated a threefold improvement in visibility due to this simple change.

Accidents are frequently caused by unusual shadows which confuse. Again there may be plenty of light, but if it is from too small, bright sources, shadows will be accentuated. This can easily be remedied by adequate diffusion of the light. Fluorescent tubes, which have been generally accepted in the short time since their introduction, are excellent from this standpoint because of their large size. Light from such sources softens shadows to the point where they are no longer annoying. Such long light sources can also be used to advantage in providing the type of visibility needed for seeing machined surfaces.

Falls on stairs are a type of accident both prevalent and difficult to eliminate. In active working areas, proper mechanical safeguards and education are often quite effective, whereas on stairs there is frequently a tendency to hurry, occasional horse play, and other factors which tend to make an accident more nearly possible. Consider the possibility of lighting the stairs properly and painting the risers a contrasting colour so that maximum visibility can be obtained. Here, as in many other cases where an accident may or may not occur due to the alertness of the man in noticing his danger, maximum illumination is an undoubted help.

More often than not the lighting consists of one lamp, either bare or in a shallow reflector at the top of the stairs. Very often this is placed so that obscuring shadows are cast by each step over the step below. Also, the steps are frequently painted black, a dark grey, or have no paint on them whatsoever. In either case, what one sees is deceptive and conducive to accidents.

Quantity of light is the factor most universally controllable and also the most difficult to estimate in the entire illumination field. The eye is absolutely no judge of quantity since it is affected so greatly by its previous adaptation. There is no direct relationship between the wattage of a lamp and the illumination received at the working plane, nor can candle-power be taken as a measure of the quantity of light which is being received where it is needed. The only simple way of ascertaining what illumination is being received is to use one of the small, portable inexpensive light-meters which give an accurate indication of light at any given point.

This gives a direct reading of the foot-candle illumination received on the plane in which the sensitive cell lies. If the light meter is not placed at the correct angle incorrect readings will be secured.

A general idea of the amount of illumination represented by foot-candle values can be obtained by holding a newspaper at different distances from a bare 25-watt tungsten filament lamp, so that the light rays fall perpendicularly upon the surface. For 16 foot-candles the distance should be fifteen inches; for 8 foot-candles, twenty-one inches; for 4 foot-candles, thirty inches; for 1 foot-candle, five feet; for ¼ foot-candle, ten feet.

In this connection it should be realized that the brightness of the surface will depend not only upon the foot-candles of incident illumination, but also upon the nature of the surface. That is, with equal illumination, white paper will be much brighter than cast-iron. It is impractical, frequently misleading, to attempt to estimate foot-candle values simple by viewing an illuminated surface.

In the instrument there is a light sensitive cell, and light falling on this

sets up a current which varies according to the amount of light, and which is indicated on the dial. There are no adjustments to be made.

To test the general lighting, hold the instrument horizontally well away from the body, three feet from the floor, so that no shadow falls upon it. Care must also be taken to hold it in such a way that the hand does not interfere with the light falling on the light cell.

The removable cover enables readings to be multiplied by five or ten, according to the maker of the instrument. Different kinds of lamps affect the instrument differently and a list of corrective factors is supplied with the instrument. Do not use a light meter to compare the total light output of two lamps, either bare or in fittings, since the distribution of light from the lamps may not be similar.

The safety officer in a factory will find a light meter invaluable. With its help and a knowledge of the simple fundamentals discussed earlier in this chapter he can determine in many cases whether seeing conditions are likely to be hazardous either for short or for long periods. It will prove to him that in many workshops the available daylight illumination is entirely inadequate for efficient working and that artificial light is needed to supplement the meagre natural light.

The illuminating engineer has also benefited in recent years by the development of a visibility meter which measures relative quantities and qualities of lighting in terms of seeing ability. This instrument is now available in several types which also extend the practical measurements which can be made of visual conditions.

The many benefits of good industrial lighting have been determined by progressive management. Among these are increased production; a greater accuracy of workmanship which results in an improved quality of products with less spoilage and re-work; a more complete utilization of floor space; a greater ease of seeing, especially among older, experienced employees, thus making them more efficient; improved morale among the employees which results in a decreased labour turn-over; more easily maintained cleanliness and neatness in the plant as well as fewer accidents.

There is an important psychological effect connected with cheerful, pleasant, modern working surroundings as compared with the dim, gloomy interiors that are still too prevalent. In addition to the more cheerful appearance of a well-lighted interior, there are many minor frustrations due to poor lighting which continually harass the workman—such as the difficulty in reading scales, finding the proper drills or other tools, etc., which if continued day after day often instil a spirit of defeatism, a most undesirable condition among a factory personnel at any time.

In the opinion of a large number of employers who have recently improved their lighting, the better morale noticed after the relighting was one of the most important benefits obtained. Employees definitely liked better lighting.

Here are some recommended minimum standards of illumination for industrial interiors:

Precision work, over 50 foot-candles; severe and prolonged visual jobs, 25 to 50 foot-candles; critical and prolonged visual jobs, 15 to 25 foot-candles; ordinary visual jobs, 10 to 15 foot-candles; casual visual jobs, 10 foot-candles; rough visual jobs, 6 foot-candles. In the Appendices will be found a comprehensive table of foot-candle intensities recommended for use in various industrial interiors.

CHAPTER FIVE

SOURCES OF LIGHT

FACTORY owners in most industries are particularly interested in making the best possible use of their daylight facilities so as to render useful and valuable all parts of the floor space and also to shorten the period when artificial lighting is needed.

The saw-tooth or skylight windows of modern factory construction permit of an adequate and more uniform daylight illumination of the entire floor area, and are desirable when practicable. When workshops are illuminated through side windows it is often difficult or impossible satisfactorily to light all parts of the floor area, furnishing adequate illumination to the workers without subjecting some of them to objectionable glare.

In some instances it is desirable to use the proper type of refracting or diffusing glass which redirects the rays of light and improves the distribution of daylight in the room, especially in the parts remote from the windows.

If only one wall contains windows, the width of the room perpendicular to the wall should be less than twice the height of the top of the windows above the floor ; if windows are in two parallel walls, the width of the room between these walls should not exceed six times this window height.

A saw-tooth roof gives best results when its width is about half the width of the building, and the height of the windows in the saw-tooth is one-half of its width. The height of the windows in saw-tooth construction should be at least one-third of the span. In general, single-storey industrial buildings should have a window area of at least 30 per cent. of the floor area.

Reflection of daylight from surfaces outside a building has an important effect upon the lighting of a workshop. Faces of structures, walls of courts, and roofs of saw-tooth buildings should be finished in the lightest practicable colours and so maintained. The possibility of glare from such surfaces should, however, be considered.

Windows should be equipped with adjustable devices so that the illumination may be accommodated to changing exterior conditions. Window blinds of light tones should be used, for at night they will reflect artificial light back into the room ; blinds transmitting diffusely a large part of the natural light they receive will usually improve the daylight illumination. When practicable, blinds should be mounted so as to permit the covering of any desired parts of the windows.

Louvres employing reflecting, diffusing surfaces are an effective means of controlling the distribution of natural illumination as well as the glare from windows, if properly finished and adjusted. Any devices for adjustment of natural lighting should be controlled by some specified individual.

Rapid changes in illumination levels result in dangerous, even though temporary, inability to see, due to the time required for adaptation of the eyes. An example of this is when one steps from bright sunlight into a dimly lighted interior.

A passageway adjacent to a highly illuminated area, therefore, needs relatively high and graduated illumination. Again, where the eye has been afforded the advantages of a high level of illumination throughout the day, and artificial light is turned on to reinforce the failing natural light, a

higher total illumination is usually needed than at night under artificial light alone.

When planning a new factory building or other work-place the design should be such that the foot-candle values for daylight should be at least twice those recommended in the Appendices. The natural lighting is frequently many times these figures ; in fact, illumination of 100 foot-candles or more can be measured near the window in almost any shop.

Natural light is subject to variation throughout the day and no individual can be relied upon in practice to determine by visual observation when more light should be added in the room or when artificial light can be spared.

Practical equipments utilizing light-sensitive cells have been developed for automatically controlling the lighting. These photo-electric relays can be relied upon to follow the changes of daylight and make corrections when needed, even though the variation is so gradual as to escape attention. They will turn on the artificial lighting when the natural illumination at a given point in the room falls below a predetermined value. If the daylight illumination then increases sufficiently they will turn off the light. The photo-electric relay does not make mistakes. It assures good seeing conditions at all times with a minimum expenditure of electricity for lighting consistent with this result.

Automatic control is recommended, particularly in positions where critical seeing is done with daylight illumination. Frequently a man engrossed in his work will not notice the gradual diminution of daylight until he realizes that he has a headache or reaches the point where he simply cannot see. When this happens to an entire department the loss in employee efficiency is serious. The photo-electric relay stands guard over such eventualities. It is an inexpensive means of avoiding the penalties of insufficient illumination when reliance is placed on daylight as the principal source of light.

The illuminating engineer deals with the application of artificial light to the scientific needs of factory and office workers. His principal aims are :

1. The adequate and even illumination of the entire plane of work without glare.
2. The elimination of dark shadows.

The choice of lamps in a well-planned installation requires as much consideration as any of the other tools used in industry, since on their efficient performance depends the possibility of carrying on work during the hours when daylight fails.

The one and only purpose of electric lamps is to convert electrical energy into light, and the value of a lamp therefore depends solely and absolutely on its ability to do this economically.

In order to appreciate the historical importance of electric lamps to industry it is perhaps interesting to point out in retrospect the development of incandescent lamps from the early parchmentized thread filament to the modern gas-filled tungsten lamp of to-day.

Common impression to the contrary, the first patent granted on an incandescent lamp was granted in 1841 to Frederick de Moleyns just a few years after Michael Faraday had discovered the basic laws of the dynamo. No outstanding progress was made until the years 1877–80, when Sir Joseph Swan patented his parchmentized thread filament and simultaneously Thomas Edison in the United States perfected his carbon filament. The Edison lamp had four outstanding improvements : (1) It was a high-

resistance lamp ; (2) the lamp was entirely enclosed in glass ; (3) it operated in a high vacuum ; and (4) the carbon filaments were held in place by platinum parts. A year later Edison brought out the carbonized bamboo filament. This lamp had an efficiency of 1·6 lumens per watt.

These early carbon filaments were very fragile. But their chief disadvantage lay in the distinctly yellow cast in the light—the reason being too low a temperature of the filament. Since these filaments were already operating just under the vaporization temperature, nothing could be done about it.

A real improvement came with the introduction of tantalum metal for filaments, which permitted much higher temperatures to be attained. In 1910, however, after long and brilliant research, Dr. W. G. Coolidge succeeded in drawing out into a very fine thread the hard, tough metal tungsten. This accomplishment was the turning point in the manufacture of electric lamps, for tungsten filaments may be raised to the incredibly high temperature of 4,800 degrees Fah., with the result that the emitted light began to approach the texture of sunlight. The efficiency of this lamp was 8 lumens per watt, a fivefold increase over the carbon lamp.

It was soon found that this new evacuated tungsten filament lamp became black with continuous use, due to the rapid evaporation of tungsten. In 1913 Dr. Irving Langmuir introduced the inert gas, nitrogen, into the lamp. The presence of this gas materially reduced the rate of evaporation of tungsten and in addition permitted the temperature to be raised. The present gas-filled lamp contains argon, with just a little nitrogen. Lamps of this type are being manufactured with efficiencies ranging from 8 to 30 lumens per watt.

Other developments of comparable importance were the introduction of the tipless lamp ; the inside frosting process which diffuses the light properly and thus eliminates glare ; and finally the replacement of the straight filaments by the highly efficient helical ones.

To-day there are some 6,000 types of lamps, from the ½-watt lamp used

Efficiencies of Light Sources

	Lumens per watt.
1879—First carbon lamp	1·4
1880—Carbonized bamboo filament	1·6
1886—Squirted cellulose filament	2·5
1896—Treated cellulose filament	3·5
1905—Metalized carbon filament	4·0
1906—Tantalum filament	5·0
1910—Drawn tungsten filament	8·0
1913—Gas-filled lamp	8·0 to 25·0
Neon lamp	20·0
Carbon arc	20·0
Mercury arc	40·0
Sodium lamp	60·0
1938—Fluorescent lamp	about 75·0

in surgical instruments to commercial lamps of 30,000 watts. Sodium vapour lamps which give rise to a characteristic yellow light are now successfully used for street and floor lighting. This lamp, which utilizes the principle of fluorescence, has an efficiency of 60 lumens per watt. Other lamps used for definite commercial purposes are the mercury vapour lamp, with an efficiency twice that of the best tungsten incandescent lamp, and the neon lamp, which has the unusually high efficiency of 20 lumens per watt.

There are three factors which, taken together, determine the quality of a lamp—light, life and uniformity—and in considering these factors it must be borne in mind that light and life are interdependent. Any given size of lamp can be made to give any desired amount of light, but in doing so its life will be seriously affected. An ordinary 100-watt lamp just glowing will last for years ; if burning at its normal brightness its life will be in the neighbourhood of 1,000 hours ; but if forced to give double its normal light it will only last for 50 hours or less.

The only metal filament lamp of the vacuum type in use to-day has a filament of tungsten, with the air removed from the bulb. The efficiency of this lamp is considerably higher than that of its predecessor the carbon lamp, but mere substitution of tungsten for carbon did not eliminate the tendency of the filament to evaporate and blacken the bulb. In about 1918 practical means were found to increase the light from tungsten filament of all but the smaller sizes, and to reduce the blackening effect of filament evaporation.

The incandescent filament of a lamp runs at an extremely high temperature at which evaporation can take place readily, but the rate of evaporation of tungsten depends largely on the external pressure. In the case of a vacuum lamp the pressure is practically *nil,* and therefore the rate of evaporation is at its highest ; but if the pressure can be raised to some appreciable value then the rate of evaporation will be slowed down and the blackening effect will be less evident.

In a gas-filled lamp an inert gas, such as argon or nitrogen, which does not attack the filament chemically, is inserted into the bulb with the sole object of providing a pressure therein. At the same time, the gas unfortunately has a cooling effect on the heated filaments it surrounds, and means had to be found to reduce this cooling effect while at the same time maintaining pressure.

The method adopted is to coil the filament into a very close spiral through which the convection currents of gas do not have a free passage. The effective surface which the filament presents to the gas is therefore that of a comparatively short thick cylinder, instead of a very long thin wire, and it will be obvious that the amount of heat carried away by convection will be considerably reduced.

Thus, by filling the bulb with gas and by coiling the filament it is possible to heat the filament to a higher temperature, and so obtain more light, while at the same time keeping the evaporation of the filament and therefore the blackening of the bulb under control.

The latest major development in tungsten filament lamp manufacture is the production and the use of the coiled-coil filament which is really an elaboration of the single coiling.

By the second coiling of the already coiled filament the effective surface presented to the convection currents in the gas is further reduced so that the loss of heat to the gas is also reduced and the lamp is therefore made more efficient.

Many people still believe that the filament of a coiled-coil lamp runs at a higher temperature than that of an ordinary gas-filled lamp. But this is not so. If it were the life of the lamp would be shortened. Actually both temperature and life are the same. A simple explanation for the extra efficiency of the lamp is this :

Due to the reduced loss of heat to the gas the temperature of the filament would, other things being equal, tend to rise, and to prevent this it is made slightly longer. This, however, has the effect of reducing the wattage of the lamp, but as it is desirable that the rated wattage of the various types of lamps should be similar, the diameter of the filament wire is slightly increased to bring the wattage back to normal. A coiled-coil filament wire, therefore, is slightly longer and slightly thicker than that of a single coil, and runs at the same temperature, but as the volume of the incandescent metal is greater it will emit more light.

A further incidental reason for the extra light output is the fact that the more compact filament of a coiled-coil lamp can be retained in position by fewer supporting wires, each of which is responsible for a drop in filament temperature at the point of support.

The efficiency of a lamp is the ratio of the luminous output to the input of power. It is expressed in lumens per watt.

The increase of efficiency of coiled-coil lamps compared with single-coiled lamps of equal wattage is as follows (200 to 260 volts) : 40-watt coiled-coil lamps give an increase of light of 20 per cent. ; 60-watt, 15 per cent. increase ; 75-watt, 12½ per cent. increase ; 100-watt, 10 per cent. increase.

Electric discharge lamps have been developed in recent years and have great industrial possibilities. A brief explanation of the functioning of an electric discharge lamp is as follows :

Cosmic rays and other ionizing agents are continually producing ions in the air and in the gas or vapour enclosed in a discharge tube, these ions being tiny particles of matter free to move under the influence of voltage. If a voltage is applied to the ends of the tube the ions will move along it, colliding occasionally with atoms of gas. If the voltage is low the ions will merely rebound, but when the voltage reaches a critical value the ions will be moving so fast that the force of collision will tend to displace one or more of the electrons, revolving round the atom, into an unnatural orbit. These displaced electrons rapidly return to their normal orbits, and in doing so give up all the energy they have absorbed. This emitted energy takes the form of electro-magnetic radiations at certain definite frequencies, which, if the gas and operating conditions are carefully chosen, are visible ; the frequency of radiations is characteristic of the gas, and the intensity of each frequency varies with the gas or vapour pressure.

If the operating voltage is increased above the critical value, the energy imparted to the moving ions may result in the expulsion of an electron from the gas atom when the moving ion and the atom come into collision. When this condition occurs the atom and the expelled electron themselves become ions, and in moving along the tube under the influence of the applied voltage they may cause more collisions, thus producing a further supply of ions. The effect may be likened to the growth of a snowball. Thus it will be seen that after the critical voltage is passed the current in the lamp will increase of its own accord unless some limiting device is used to check it.

An electric discharge lamp consists essentially of a gas-tight tube filled with gas at a very low pressure (to allow the ions plenty of room to get up

speed before the collision), with an electrode sealed into each end, with a device for providing the higher voltage per unit length necessary for starting, and with automatic limitation of current when running.

It is found that considerably more current can be passed by the electrodes, without damage to themselves, if they contain compounds of alkaline earths which are heated so as to emit electrons freely. The greater current density in 'hot cathode' lamps naturally results in a greater amount of light, and lamps of this type can be run on ordinary mains voltage.

Mercury type electric discharge lamps command great attention from progressive lighting engineers. The essential parts of this type of lamp are :

1. An inner tube containing argon at low pressure, and a little mercury, with one main electrode at each end and an auxiliary starting electrode at one end.
2. A special starting resistance.
3. An outer glass tube or bulb, in which the inner tube is centrally supported, the space between the two tubes being exhausted of air in order to prevent the formation of cold spots on the inner tube, due to which the mercury vapour might condense.
4. The ends of the inner tube are often silvered to assist in maintaining the heat, particularly in the region of the electrodes.

On first switching on, the applied voltage will not start a discharge between the main electrodes, as the voltage gradient is insufficient. However, there is an auxiliary electrode very close to the main electrode and the voltage gradient at this point is sufficient to start a discharge in argon across this small space. Immediately this discharge starts the gas becomes ionized, and the discharge between the two main electrodes takes place. The current in the auxiliary starting circuit is limited by means of a 50,000-ohm series resistance, and it can therefore be disregarded after fulfilling its purpose in initiating the discharge.

The discharge in argon is rapidly displaced by a discharge in mercury vapour, and as the heat of the discharge vaporizes the mercury and raises the vapour pressure, so the brilliance of the arc increases until after about five minutes (in the case of the larger lamps) it appears as a narrow cord of light stretched between the two electrodes. The smaller sizes of lamps run up to full brightness in a considerably shorter time.

If small sizes of mercury discharge lamps were to be made in the same form as their larger counterparts, their comparative efficiency would be rather low, although still very considerably higher than that of equivalent tungsten filament lamps. It was found, however, that by raising the pressure of the mercury vapour, by enclosing it in a smaller tube which has to be made of quartz, to withstand the high temperature, the efficiency is brought back to approximately that of the large lamps. These smaller mercury lamps, with their familiar pear-shaped bulbs, are able to take the place of many similar-sized tungsten lamps, with obvious benefits under certain conditions.

The voltage necessary to start a discharge depends partly on the pressure of vapour in the discharge tube. When hot, a mercury discharge lamp has an appreciable internal pressure, and the ordinary mains voltage is insufficient to restart the discharge, after switching off, until the lamp has cooled down and the pressure fallen to a lower value. If the switch is left in the 'on' position the lamp will restrike automatically as soon as this condition is reached.

Mercury discharge lamps of 400- and 250-watt sizes should be burnt

vertically cap up (or cap down if specially designed) or within a small angle to the vertical, unless special steps are taken to ensure that the arc is made to occupy the centre of the discharge tube itself. Lamps of 125- and 80-watt sizes can be burnt in any position.

A table showing the operating characteristics of ordinary mercury lamps is given on page 117 of Appendices.

A sodium discharge lamp functions in a similar manner to a mercury discharge lamp except that the discharge is first started in neon and is then continued in sodium vapour.

The time taken for these lamps to reach full brightness is up to fifteen minutes, varying with the size of the lamp, but owing to the fact that it is essentially a low-pressure lamp the arc will strike immediately it is switched on, whether the lamp is hot or cold. Its brightness at the moment of switching on will, of course, depend on the state of vaporization of the sodium. Sodium lamps are available in 45-, 60-, 85-, and 140-watt sizes. The normal burning position is horizontal, but the two smaller sizes may also be used vertically, cap upwards. A table showing the operating characteristics of sodium lamps is given on page 117 of Appendices.

It has already been explained that a device is necessary to limit the current flowing in an electric discharge lamp. The usual method employed is to insert a choke in the 'phase' lead of a mercury lamp, and to supply a sodium lamp through a 'leakage transformer' with the primary winding connected to the mains and the secondary winding to the lamp. Chokes and transformers, however, are both reactors which cause the circuit to have a lagging power factor, i.e., the current flowing in the mains will actually be greater than that to be expected with a lamp of given size. In the majority of cases it is desirable on economic grounds partly to rectify this state of affairs, and it can be done quite simply by connecting a condenser across the mains. Charges for current will thus be reduced.

Chokes and transformers will each absorb a small amount of power, which should be added to the rated lamp wattage in order to find the true wattage of the lamp circuit. Details of approximate operating data can be obtained from the manufacturers of the lamps it is proposed to use.

The condenser must be connected across the *mains* and not across the lamp terminals. One choke or transformer is needed for each lamp, but proportionately larger condensers may be used to serve a group of lamps.

CHAPTER SIX

FLUORESCENT TUBULAR LAMPS

RESEARCH laboratories have recently developed a new electric lamp operating upon physical principles basically different from those of the incandescent lamps discussed in the previous chapter. This new fluorescent tubular lamp is a more efficient source of light than the best of the available tungsten filament lamps.

The guiding principle that led to the development of the present tungsten lamp is this: Every object when heated to a sufficiently high temperature will begin to emit light—the higher the temperature the more like sunlight does this radiation become.

In spite of the fact that the technique of producing illumination has been eminently successful in providing a convenient and quite adaptable source of light, it is nevertheless a technique of sheer awkwardness and brute strength, for of all the electrical energy used, say in a 60-watt bulb, only 6 per cent. is useful energy, that is, energy in the visible light range. The rest is wasted in the form of heat. Stated practically, of every million pounds spent on electrical energy each year for lighting purposes £940,000 is wasted !

It is this fact that has given research laboratories impetus to investigate sources of illumination. Although the efficiency of incandescent lamps can be improved by increasing the temperature of the filament, there is a practical limit to which this can be done. In order that a hot body shall emit the maximum amount of energy in the useful visible range, the body, theoretically, must be heated to the fantastic temperature of 10,000 degrees Fah. ! All known substances vaporize before reaching this temperature.

The research physicist has pushed his investigations along entirely new lines, using as a clue this simple basic fact : If light from the sun (the ideal to be attained) is analysed by allowing this radiation to enter a prism of glass, which has the property of resolving light into its spectrum colours, the original light is found to be nothing more than a mixture of colours ranging from deep indigo through violet to red in the visible range and bordered on both sides by the invisible infra-red and ultra-violet. Moreover, it is found that of the radiation of the sun that can stimulate the retina of the eye 38 per cent. can be roughly classified as red, 37 per cent. as green, and 25 per cent. as blue. These three colours, red, green and blue, are known as primary colours, for any other colours in the spectrum can be matched, in so far as the eye is concerned, by an appropriate mixture of primary colours.

As early as 1680 Newton learned that white light could be approximated by mixing just two colours, known as complementary colours. The sensation of white produced by the mixture of two colours, however, is a physiological effect. Blue and yellow of the proper tints and intensities will make white ; also, green and red may be complementary. In order to completely match sunlight, of course, it would be necessary to blend all the colours of the white light spectrum. But since the eye cannot appreciate the entire gamut of colours, the physicist has taken advantage of the fact in blending 38 per cent. red with 37 per cent. green and 25 per cent. blue to obtain a mixture that is visually sunlight. This is what is effectively done in the fluorescent lamp.

The phenomenon of fluorescence, briefly explained, is this : Light from an ultra-violet, for example, is absorbed by the atoms of an element ; the energy of the absorbed waves, instead of appearing simply as heat, as is generally the case, produces an excitation of the atoms, and the energy shifts during the readjustment to produce light waves from these atoms—light that is characteristic of the atoms, not of the exciting waves. In the case of sodium vapour the fluorescence is marked by a beautiful yellow colour.

Electrons from the wire are shot into the mercury vapour, exciting the mercury atoms so that on reorganization to their normal state they emit intense ultra-violet light. This light is allowed to irradiate the shell of a tube that contains thin coatings of the proper fluorescent materials, causing these salts to strongly fluoresce—some red and yellow, others blue and green. This mixture of coloured radiations is what the eye identifies as white

light. Not only are these new lamps capable of producing white light, but by proper choice of fluorescent material many delicate hues hitherto impossible are available.

Fluorescent lamps have several characteristics recommending them for industrial illuminating purposes.

1. They economically produce light of daylight colour quality.
2. They permit higher levels of lighting to be obtained with existing wiring, if power factor correcting equipment is used at the lamp.
3. They produce cooler illumination. With their use it is now possible to provide 100 or more foot-candles without discomfort from heat.
4. They are large-area low-brightness sources and therefore provide lighting of good quality.

Although the physics of light production of these lamps is complicated, they are simple in form and easy to operate.

The operation of fluorescent lamps involves the fundamental principles

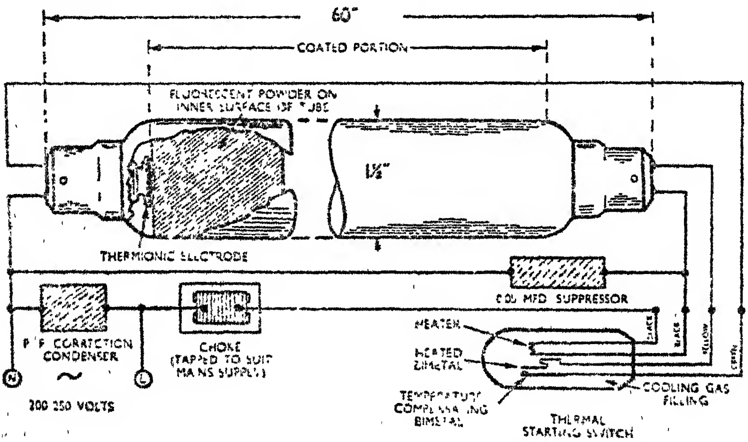


FIG. 2.—MAZDA FLUORESCENT LAMP AND AUXILIARIES

of fluorescence which have long been of scientific interest. It is an electric discharge device making use of ultra-violet energy to activate a fluorescent material coated on the inside of the bulb surface. The powdered material may be one of several or a mixture of definite inorganic chemicals known as phosphors. The phosphor powders transform short-wave invisible radiation into visible light. They are made synthetically because they must be carefully controlled for composition, purity and physical condition to obtain uniformly high efficiencies. The fluorescent powder must respond to the particular type of ultra-violet generated.

The lamps are really hollow tubes capped at each end with standard bayonet caps, thus necessitating flexible socket connections. These external contacts are connected to filamentary thermionic electrodes made of coiled tungsten wire. The filament electrodes are coated with an active electron emissive material. Inside the bulb there is a small globule of mercury and also a few millimetres of pure argon gas at a pressure of about 1/200th of an atmosphere to facilitate starting. After starting, the current is carried essentially by the mercury vapour. It remains at a low current density and

allows only a small temperature rise, resulting in a low vapour pressure. Under these conditions the desired resonant radiation of mercury is efficiently produced.

Fig. 2 shows the lamps in some detail, part of the glass being broken away to reveal one electrode and the position of the powder layer. Owing to the low temperature at which the lamp operates, approximately 40 degrees C., the fluorescent powder can be safely accommodated on the inner surface of the glass tube, and no outer jacket or special powder support is required.

The dimensions of the lamp are chosen carefully to meet the interdependent factors of mains voltage, lamp wattage and the conditions governing efficiency of U.V. (2537 Angstoms) production. This efficiency falls with increase of current density and so a large diameter tube is chosen. The lamp voltage drop decreases with tube diameter, however, and for economy in choke design and power factor correction condenser capacity a diameter is chosen which will give the correct voltage drop with a reasonable tube length. There is an optimum temperature for U.V. production, and lamp dimensions and wattage have to be such as to give this. The final decision on size depends, therefore, on correct technical selection from a complex set of conditions.

The colour of light for fluorescent lights depends principally on the chemical nature of the powder, but physical form is also important for efficiency and ease of application. A number of colours have been perfected, but only the 80-watt tubular fluorescent lamp is at present on the British market.

The light from fluorescent lamps is made up of the broad band spectra produced by the fluorescent powders and also by the characteristic visible live spectrum produced by the mercury vapour; the latter is incidental to the production of the short ultra-violet. The light from the live spectrum is predominantly blue and influences the resulting colour of some lamps to an appreciable extent, since there would be 3½ lumens of mercury light for each watt of input if the fluorescent powder were left out of the bulb. Actually, the percentage of the total radiation represented by this mercury live radiation depends, of course, on the efficiency and colour characteristics of the phosphor in any particular type of lamp. It is a small percentage of the total light in the case of the green lamp where the efficiency is high, while it is more pronounced in the case of pink lamps. In the case of the red, where the additional red colour coat is used, very little, if any, of the visible mercury lines get through, being absorbed by the red coating.

Single phosphors which produce their own characteristic spectral curves are employed in the five coloured lamps. In the white and daylight lamps, however, three specially selected phosphors in proper proportion are used in each so that a more nearly continuous spectrum is obtained. Thus, by varying the mixtures, definite colour temperatures can be standardized.

The white fluorescent lamp is the result of many trials and experiments with the idea of producing a source of light having a warmth to its character and under which people, etc., would have a pleasing yet reasonably natural appearance. All of the colours are present, and although their distribution is not similar to that of an incandescent solid they are so proportioned that results are quite satisfactory. The colour temperature is close to 2800 K, but this light source cannot be directly compared to a black body radiator.

The daylight lamp has a colour temperature of 6500 K, which is the recognized standard value for natural daylight, and represents the light

from an overcast sky. The three phosphors in it have been so mixed that their light covers the visible spectrum and the mercury lines approximately make up for the depressions except in the red region. There is no satisfactory phosphor available which can adequately augment the deep red. The eye is not very sensitive in this region, however, and the lack of some red and the other more minor irregularities are not easily detected in use.

Fluorescent lamps, in common with other discharge lamps, have negative volt-ampere characteristics and require some sort of auxiliary equipment to operate them. The elements comprising the auxiliary are (1) an iron-core choke coil which limits the arc current, and (2) a starting switch which momentarily closes and then opens the electrode heating circuit. Each lamp requires a separate auxiliary, though the elements for two lamps may be in a single container. Specifically designed ballast equipments are required for each wattage size, for each frequency and for each voltage range.

The starter switch is the element most likely to cause trouble, either by breakage in stock or in use. The usual system employs the replaceable starter, facilitating the discovery of switch trouble and simplifying wiring.

The starter switch has to comply with very definite requirements in addition to automatic operation:

(*a*) Reliability in service with a long life covering many thousands of operations.

(*b*) Small size and economic construction.

(*c*) It must open as soon as, but not before, the lamp electrodes have reached operating temperature.

(*d*) It must *hold open* over all normal and many abnormal variations in live voltage.

(*e*) It must re-close quickly when the lamp is switched off so as to be ready to re-start the lamp at once if required to do so, and it must not chatter.

The thermally-operated starter consists of two bi-metal contact arms, one of which is operated by an adjacent heater connected in series with the lamp, the other serving as a compensator to render the switch independent of changes in ambient temperature. These elements are hermetically sealed in a small glass bulb filled with gas which gives the switch the desired quick operation. In the Mazda thermal glow switch the heater is replaced by a glow discharge between the two bi-metal arms. To simplify starting this equipment has been made so that the electrodes are pre-heated. This makes lower starting voltages possible.

Details for operating fluorescent lamps vary with individual makers.

In the Mazda design the thermal glow switch permits current to pass through filament type electrodes until they are hot and emit a copious supply of electrons, and then to arrange that a voltage higher than the mains be momentarily available. This causes a spread of ionization along the length of the tube and the mercury vapour becomes conductive.

Once ionization occurs, current passes freely through the lamp and its resistance falls with increasing current. Due to this 'negative resistance' characteristic of the lamp it is necessary, as with other electric discharge devices, to connect a stabilizing choke in series. The choke reduces the power factor so that a condenser is necessary to bring it up to 0·85 or more.

Separate means of electrode heating are necessary only for a second or

so while the lamp starts, for after this the electrodes are designed to be self-heating by the discharge current. It is also necessary at the starting period to supply a momentary high voltage.

In the usual type of design the thermal switch permits current to pass through the electrodes until they are hot and emit a copious supply of electrons, and then to arrange that a voltage higher than the mains be momentarily available, this switch opening, automatically allowing the arc to strike. An inductive kick from the choke as the switch is opened gives a safety factor in starting. The momentary (approximately one second) starting current may be about $\frac{1}{2}$ ampere for each lamp with its equipment, while the operating current is less than $\frac{1}{3}$ ampere.

It is obvious, however, that occasionally the switch will open when the voltage is close to the zero point in the cycle, when the lamp will not start. In such cases there is about three or four seconds delay until the switch can operate a second time.

Of the several types of starter switches the thermal starting switch is lowest in cost and provides positive pre-heating conducive to long lamp life. The magnetic switch circuit provides quick starting at reasonably low cost. Switch circuits cannot be expected to be satisfactory if line voltages are more than 10 to 15 per cent. below normal because of inability of the switches to hold open.

The light output of fluorescent lamps is not affected by variations in line voltage to the same extent as filament lamps. The wattage delivered to the lamp is influenced, of course, by the type of operating equipment and by the characteristics of the chokes in that equipment, but in general, with the ordinary type of auxiliary using no capacitance it may be said that a 1 per cent. change in line voltage means a 2 per cent. change in lumens from fluorescent lamps instead of a 3 per cent. change in lumens in filament lamps.

It is interesting to note that as the line voltage goes up the lamp voltage goes down, and although the lumen output increases the efficiency decreases. Reasons are—the increased line voltage causes the choke to pass more current to the lamp which lowers the resistance of the discharge path and produces the lower voltage drop.

The watts input to the lamp are slightly increased and therefore the lumens increase over a certain range, but because of the higher current density in the discharge space the short ultra-violet radiation is generated less efficiently. Consequently the luminous efficiency of the lamp decreases.

The lamp is designed to give its best all-round performance at the specified wattage. Lowering the wattage will not necessarily increase the life of the lamp as is the case with filament lamps, because such treatment places a greater burden on the electrodes, causing them to operate too cool and to be bombarded too severely. On the other hand, excessive wattage also causes a shortening of the life due to the more rapid use of the active material of the electrodes.

Since the fluorescent lamp operates best when mercury vapour pressure is at a certain value it can be said that it is influenced by ambient temperatures. During normal operation with ambient temperatures of 70 to 80 degrees Fah., the $1\frac{1}{2}$-inch lamps operate at 104 to 113 Fah. When the ambient temperatures become higher, such as at 90 or 100 degrees Fah., there is a very slight falling off in lumens. At the lower temperatures, however, there is a more serious decline in lumens so that when the thermometer is near freezing point a lamp gives only about 25 per cent. of its normal lumens if

burned in the open with still air and no protection. This condition may be very largely corrected by using cones, reflectors, shields, etc. For example, with an ambient temperature of 74 degrees Fah. an 18-inch by 1-inch lamp gave 100 per cent. lumens, while at 15 degrees Fah. it gave 8 per cent. lumens. The same lamp in a fully enclosing jacket of a high-quality translucent plastic gave 80 per cent. normal lumens at 15 degrees Fah.

Practical lamps are designed so that the bulb temperatures under normal operating conditions are just above the peak value. Movement of the air reduces the bulb temperature to a given air temperature, and to cover conditions encountered in industrial lighting installations, the bulb temperature has been placed safely above the peak.

It is probable that the variation of the light output with temperature may be noticed visually, after starting a lamp on a cold day. The lamp bulb temperature is initially that of the air, and if this is low in temperature the light output may noticeably increase as the lamp warms up.

Fluorescent light is sometimes referred to as cool light, and there is justification. In addition to requiring less watts for a given output, fluorescent lights actually radiate less heat per lumen than filament lamps. A standard 40-watt opal filament lamp gives about 475 lumens and radiates 78 per cent. of its input, or about 31 watts; this radiation is mostly infra-red. The 80-watt white fluorescent light gives 2,800 lumens, but radiates only 47 per cent. of its input, or about 37 watts when used bare. This means that for equal lumens from lighting installations using the two types of lamps there is approximately one-quarter as much heat radiated from the fluorescent lamps as from incandescent lamps. Most of the waste energy is conducted from fluorescent lamps, while with incandescent lamps it is largely radiated. In the one case much of the heat stays near the lamps, usually in the upper parts of a room, while in the other the heat may fall directly on the persons and other objects in the room. The advantage of the lesser radiated heat, from the comfort standpoint, and in connection with air conditioning, is obvious. However, the total heat will be a direct ratio of the wattage employed.

Fluorescent lamps, being electric discharge lamps, have somewhat the same characteristics as mercury sodium lamps with respect to the lack of constancy of light flux due to the alterations of the current upon which they are operated. The fluorescent powder, however, has in most cases a persistence of glow, known as phosphorescence, which tends to reduce flicker effect. The fluorescent lamp has a characteristic stroboscopic effect about half-way between those of incandescent and electric discharge lamps.

In the case of ordinary tungsten filament gas-filled lamps working on an alternating current circuit, the filament tends to become cooler and hotter in accordance with the cyclic variation of current flowing in it, but due to its mass the actual variation of temperature, and therefore the light output, is unnoticeable except perhaps with the very smallest size of lamps.

With electric discharge lamps of all kinds the arc is actually extinguished every time the current cycle passes through zero, and before electric discharge lamps came into common use in factories the fear was often expressed that the consequent stroboscopic effect might be a source of considerable annoyance. It is found in practice, however, that it is very seldom indeed that the effect is either dangerous or distracting, since even if one particular part appears to stand still the movements of other parts will make it quite obvious that the machinery is in motion.

In an attempt to group the various types of fluorescent lighting systems

on the market at present, it may be said that there are three distinct systems. The first type is the single phase system which is stroboscopic. The second is the split phase system which is partially stroboscopic. Both of these can be connected directly to the standard single phase lighting circuit.

The third type is the polyphase system which is anti-stroboscopic, with one tube connected to each phase. The latter can be connected only to a three-phase power line which is rather conventional in factories.

The flickering effect observed under some fluorescent lights which makes a wheel seem to stand still or turn backwards or a moving object to appear in a series, thus creating an illusion, is caused by light variations and is known as stroboscopic effect. This phenomenon is a cause of eye-strain and headache.

To explain this phenomenon let us refer to the simple wheel in Fig. 3. For convenience let us assume that this wheel rotates at a speed of one

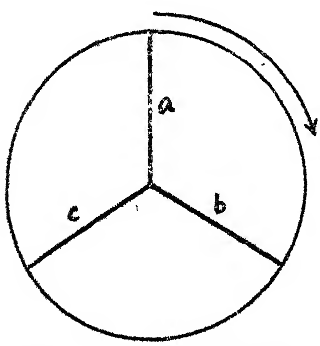


Fig. 3.—STROBOSCOPIC EFFECT

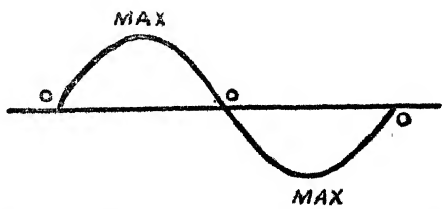


Fig. 4.—VALUE OF VOLTAGE WITH RESPECT TO TIME, IN AN ALTERNATING CURRENT CIRCUIT

revolution per second and that it receives a lighting impulse once every second. The only time spoke *a* is lighted is when it is in the top position, and during the remainder of the revolution this spoke is not lighted and hence not seen.

The same holds true of spokes *b* and *c*, hence they will be seen only in their respective positions. This makes the wheel appear to be motionless.

Furthermore, if the speed of the light impulses is not the same as that of the revolving wheel, the wheel will appear to rotate at a much slower speed that it actually does. The apparent speed will be equal to the actual difference in speeds between the light impulses and the rotating wheel. This same phenomenon illustrated by the wheel applies equally well to reciprocating motions, such as punch, shears, etc., and transient motions.

This can best be understood by observing Fig. 4 which shows the value of voltage with respect to time in an alternating current circuit.

The light emitted from a neon-type tube follows the voltage curve very closely. In other words, when the voltage is zero the light output is zero and when the voltage is maximum the light output is maximum. This causes the light output to be truly cyclic in nature and gives rise to stroboscopic phenomenon. Because of the effect of alternating current on gaseous discharge bulbs the stroboscopic effect explained above becomes very apparent.

The stroboscopic effect is reduced considerably in the split or compensated phases system because of the two phases overlapping and giving far less voltage variation than in the single phase system. The curve in Fig. 5 shows the resultant intensity variation with a two phase system and makes the reduced stroboscopic effect apparent.

The manufacturers of the polyphase type claim that their system eliminates the stroboscopic effect. This is apparent by observing that the light pulsations practically level off to a straight line as indicated by the dotted line in Fig. 6.

The resulting intensity variation of this system is now actually equivalent to an incandescent bulb operated on a single phase circuit. Practical field experience has shown that this variation is below the value discernible by the human eye.

It is therefore evident that by eliminating the light variations, the stroboscopic effect is similarly eliminated and the possibility of hazard is reduced considerably, especially in connection with the hand-feeding of power-driven presses, shears, lathes and other moving machines. Also the

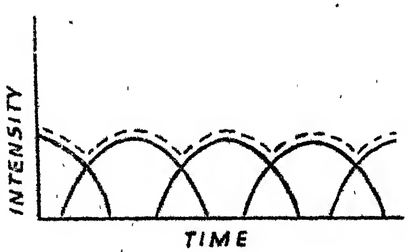


FIG. 5.—RESULTANT INTENSITY VARIATION WITH A TWO-PHASE FLUORESCENT LIGHTING SYSTEM

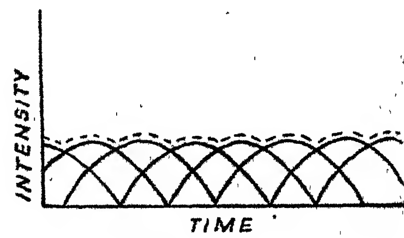


FIG. 6.—TIME-INTENSITY CURVE SHOWING ELIMINATION OF STROBOSCOPIC EFFECT

design of the reflector should be considered as it has a decided bearing on whether or not the entire anti-stroboscopic effect of these systems is utilised.

In most cases it may be desirable for psychological reasons to reduce the flicker effect, although unnecessary to do so from the safety point of view. This is easily done by either of the following methods. (*a*) If a three-phase-electric supply is available, adjacent lighting points should be wired on different phases, so that when one lamp is momentarily out, two nearby lamps are alight. (*b*) Electric discharge lamps may be used in conjunction with tungsten filament gas-filled lamps. This method will reduce but not entirely eliminate the flicker effect, and it may at the same time be used to correct the colour of mercury discharge lamp installations.

The life of fluorescent lamps is influenced by many factors—not only precision of manufacture, the circuit, the operating equipment, and line voltage, but by operating conditions. In general, lamps of this sort lose their usefulness due to lumen depreciation before they fail to operate. Darkening of the bulb occurs because (1) of the deteriorating effect of mercury on the fluorescent coating and (2) of material given off by the electrodes. The latter especially contributes to darkening at the ends of the bulb. This occurs late in life. The rate of depreciation in light output diminishes throughout life; the first 100 hours produce as much or more darkening as the following 1,000 hours. The percentage of lumens at 1,000 hours' life

may be expected to be, under normal conditions, far better than for vacuum filament lamps.

Frequent starting of lamps may take more life out of electrodes than long hours of burning because momentarily there is a higher than normal voltage drop at the electrode, which splutters off the active material. If a lamp is started once a minute, the hours of burning will be shorter than normal, but if it is burned continuously its life will be longer than normal. When the active material on the electrodes is used up, the voltage required for starting and operating becomes too high and a lamp is then considered to have failed. Usually it may be expected to live much longer than standard filament lamps.

The long length of these lamps has been found more practical because of lower lamp cost per foot and lower auxiliary cost per foot as well as because of higher efficiency.

With the development of the fluorescent lamp, industry can now provide the foot-candles necessary for the critical seeing tasks which are part of to-day's manufacturing processes. The limiting factor with high foot-candles in the past was the matter of heat. However, with the radiant heat from fluorescent lamps only one-quarter that of filament lamps for equal foot-candles, this factor is no longer a problem.

Maximum advantage is being taken of this cool characteristic to place the lamp close to the workman. For example, an 80-watt unit mounted about thirty-six inches above the job will produce about 100 foot-candles over a relatively large area.

CHAPTER SEVEN

INDUSTRIAL REQUIREMENTS

INDUSTRY contains many hundreds of different operations in each of which there are certain essentials which define the workers' needs. The operator must distinctly see certain features of the work in hand. Therefore illumination must be provided to ensure that these can be seen under the best conditions.

A representative survey of some 120 industries has been taken with the object of explaining briefly where and in what manner operations need light. The recommended value of foot-candles is also given. The executive will find among the operations listed a case closely parallel to any task not included, and from which the necessary lighting requirements can be judged.

Aerograph (Pottery): The lighting must be specially arranged to penetrate into the booths and at the same time the units must be suitable for use with the fumes present from the spray. (12–20 foot-candles.)

Assembly (Aeroplane): Work must go on at speed on all parts of the machine; workers at all points need light sufficiently well diffused to penetrate past obstructions and avoid casting shadows. Vertical surfaces are particularly important. (15–30 foot-candles.)

Assembly (Chassis): The operator needs to see the riveting he is doing round the frame without shadows. This applies on all sides of the frame. (10–15 foot-candles.)

Assembly (Engineering): This operation can vary so much that no

definite requirements can be stated, except that diffused lighting is usuall required to penetrate the work and to avoid reflected glare or shadow fro the workers. (15–30 foot-candles.)

Assembly (Woodwork): On account of the various shapes of th articles handled the light should be well diffused to enable the work to b seen at various angles without shadows. (12–20 foot-candles.)

Assembly Line (Motor): As the engines move down the conveyor th workers need to be able to see the parts they are dealing with. Goo diffused lighting arranged with regard to the conveyor prevents shadow and reaches the interior best. (15–25 foot-candles.)

Assembly of Small Parts: Diffuse lighting is required on the benche arranged so that shadows are not cast by the workers on their work. (12–2 foot-candles.)

Baking: Where articles are being taken out of ovens light is needed o the conveyor or trays to enable a rapid check to be made of the degree o the bake. (10–15 foot-candles.)

Bandsaw: Light is wanted on the table so that marks can be seen clearl and to avoid throwing shadows from the saw or guard. Fittings with viso glass fronts should be used to reduce cleaning. (10–15 foot-candles.)

Belt Sander: The finish of the work can best be seen by light reflecte from an illuminated matt surface beyond it. Visor glass fronts should b fitted.

Bins (Stores): The light is required on the vertical surface of the good in the bins so that items can be found and labels read without difficulty (6–10 foot-candles.)

Blake Sewing (Leather): The light is needed on the needle and on th edge of the sole so that the operator can see where he is guiding it. (15–2 foot-candles.)

Block Mounting: The circular saw and other mounting operation need good illumination at bench level. (15–20 foot-candles.)

Blowing (Wool): Predominant light should be on the front of th machine so that the cloth can be kept straight and not wrinkle as it is passed over. Enclosed fittings should be used. (8–12 foot-candles.)

Blowing into a Mould (Glass): Light is needed to enable the blowe to gather the metal and for cracking off afterwards, but especially on to the mould to enable him to centre on it correctly and to see that the mould is clean. (10–15 foot-candles.)

Boiler-room: The principal items the worker needs to see and the fuel where he takes it up, the grates and the gauges. Light should reach all these points to ensure easy working. (In many cases moisture proof fittings should be used.) (6–10 foot-candles.)

Bottom Scouring (Leather): The operator needs to see the sole of the shoe and the point where the tool is touching it. There must be no shadow at this point so that he can see clearly the part on which he is working. (15–25 foot-candles.)

Brazing: Light is wanted on the hearth and surroundings in sufficient strength to enable the worker to see clearly when the glare of the flame is withdrawn. (10–15 foot-candles.)

Carding (Cotton): The light is needed over the whole of the front of the machines so that the operator can watch the material passing through and over the machine to facilitate fettling. Visor glass fronts are recommended. (15–25 foot-candles.)

Casting (Pottery): It is necessary to be able to see clearly the entries

to the moulds to check their filling. Adequate illumination is needed on the surroundings for their handling. (10–15 foot-candles.)

CASTING STEREOS: Light is needed on to the top of the apparatus where the metal is poured, and down into it when it is open for inserting the flong and removing the stereo. (10–15 foot-candles.)

CHASSIS RIVETING: The operator needs to see the riveting he is doing round the frame without shadows. This applies on all sides of the frame. (10–15 foot-candles.)

CHOCOLATE COATING: The operator needs to see the top and sides of the cakes, as they are being covered and the light must reach all round them. (10–15 foot-candles.)

CIRCULAR SAW: Light is required on the table so that markings can be seen and so that no shadows are thrown by the saw-blade. Visor glass fronts should be fitted. (10–15 foot-candles.)

CLICKING (Leather): Diffuse lighting specially arranged to enable the quality and variations in the leather to be distinguished and at the same time penetrate sufficiently under the arm of the machine to enable the operator to see where he is setting it.

CLOSING (Leather): Light is needed at the needle point without shadow so that operator can see just where she is working. Supplementary lighting is recommended. (20–50 foot-candles.)

CLOTHING: Good lighting is wanted at the needle and care must be taken that no shadows are thrown by the machine or the operator. (20–35 foot-candles. Sometimes higher with dark materials.)

COAL PICKING: To see the varied coal on the conveyors the light needs to be correct in colour and sufficient to show up the dark-coloured materials. Daylight visor glass fronts or electric discharge with clear visors should be used. (15–25 foot-candles.)

COLD RIVETING: Light is wanted on the work as it is held over the fixed head so that the worker can see the rivet heads clearly. (8–12 foot-candles.)

COLLAR MACHINE (Laundry): The important point to watch in this operation is the feed between the two wheels where the collars are inserted. The light should reach this position from the side where the operator stands. (10–15 foot-candles.)

COPPER PLATING: Light is needed over the top of the bath and on the vertical surfaces of the stereos when they are lifted up. Porcelain well glass fittings should be used as a protection against fumes. (10–15 foot-candles.)

CUTTING OUT (Clothing): The cutter needs a good, well-diffused illumination free from shadow on the surface of the material so as to follow the marking. The shears should not throw a shadow. (15–25 foot-candles.)

DECORATING (Pottery): The artist requires the light on the surface of the article on which he is working and, if he is using colour, he requires light which will enable him to distinguish the different shades. His hand and brush should not throw shadows. (15–30 foot-candles.)

DESIGNER (Pottery): The designer needs good diffused lighting on his drawing-board which will not throw shadows from his hand or pencil—also he needs to be able to see the detail of the articles to which he has to refer. (25–50 foot-candles.)

DIPPING (Pottery): Light is needed not only over the general surroundings, but especially to penetrate the vats without shadow from operators, and on the shelves where they are placed. Porcelain well glass fittings are advisable. (8–12 foot-candles.)

DRILL (Woodwork): Light is required on the work where the drill is to be applied so that no shadow is thrown by the drill. (10–15 foot-candles.)

DRILLING (Metal): The worker needs to see where the drill is to enter and to watch it as it is fed in. (12–20 foot-candles.)

DYEING: Light is, of course, needed on the material where, for example, it is passing in and out of the vats to ensure easy and safe handling. Porcelain well glass fittings are recommended. In certain operations there is need for colour-corrected light. (8–12 foot-candles.)

ELECTRIC WELDING: Light on work where it is held between the electrodes with no shadow towards the operator. Remember the work can be held at various angles. (10–15 foot-candles.)

EXAMINATION: The light on the articles being examined must be suitable to distinguish detail. The colour of the article sometimes needs a high illumination and the colour of the background must be suitable to avoid too great a contrast. (15–25 foot-candles.)

EYELETTING (Leather): The light must reach the tool face of the machine without throwing shadows on the work or the tool. This means it must come from the sides. (15–25 foot-candles.)

FILLING SAGGARS (Pottery): There must be light inside the saggar so that the workers can insert the articles without fear of damage. (8–12 foot-candles.)

FILLING TARTS: Light is needed under the superstructure so that the operator can watch the filling of the tarts as they are moved along. (10–12 foot-candles.)

FLAT DRAWING (Glass): As the glass is drawn the sheet needs to be seen without annoying reflections from lamps overhead. (8–12 foot-candles.)

FRETSAW: Light is wanted on the table so that markings can be followed easily without the blade throwing confusing shadows. Visor glass fronts are recommended. (10–15 foot-candles.)

GALVANIZING: The operator must watch the articles carefully as they go in and out of the tank. The lighting is needed to avoid shadows and should be arranged according to the layout of the tanks. Porcelain well glass fittings should be used. (8–12 foot-candles.)

GATHERING THE METAL (Glass): The worker needs to be able to watch the metal and to follow its shape easily without high lights reflecting in its surface. General illumination is needed owing to the contrasts involved. (10–15 foot-candles.)

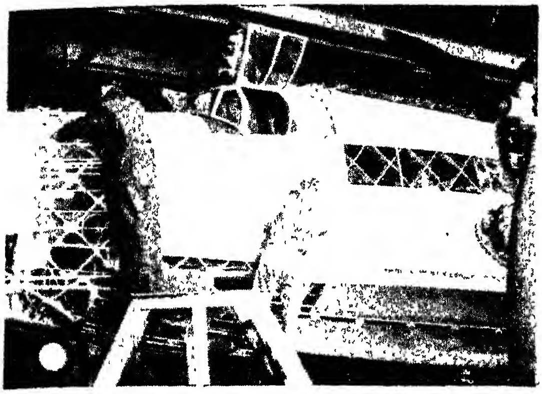
GLASS BEVELLING: The light is required on the edge of the wheel where the work is held and it should be at such an angle that reflections in the glass are not allowed to reach the operator. (15–25 foot-candles.)

GLASS PRESSING: The gatherer pours the metal into the mould, the exact quantity being cut off and general light is needed to avoid danger from hot glass. (6–10 foot-candles.)

GUILLOTINE (Engineering): It is necessary to see on both sides of the guillotine and the light should enable the sheets to be placed against the guides or measures easily. (10–15 foot-candles.)

GUILLOTINE (Paper): Ability to see well under the jaws of the machine to make sure that all the stack of paper is square against the stops. The important part to see is at the back rather than the actual blade. (12–[illegible] foot-candles.)

HAND SEWING (Clothing): Good illumination is needed on the work without shadows being thrown on it by the worker or by her hands. (20–[illegible] foot-candles. Possibly higher with dark materials.)

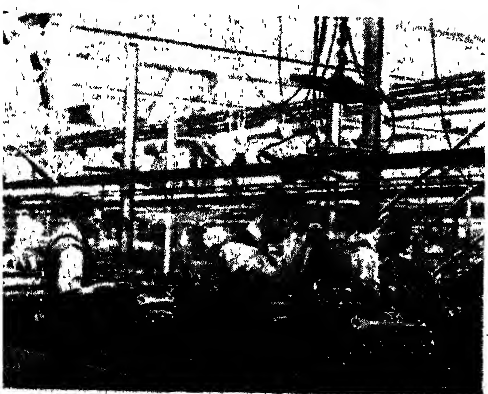


AIRCRAFT ASSEMBLY

(15–30 foot-candles : *see* page 45)

RIVETING A MOTOR-CAR CHASSIS

(10–15 foot-candles : *see* page 47)



MOTOR-CAR ASSEMBLY LINE

(15–25 foot-candles : *see* page 46)

ASSEMBLY
OF
SMALL PARTS

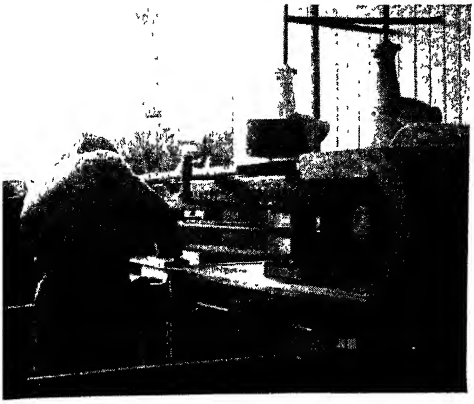
(12–20 foot-candles : *see* page 46)

MAKING CLOTHES
WITH A
MACHINE

(20–35 foot-candles : *see* page 47)

OPERATING
A
BANDSAW

(10–15 foot-candles : *see* page 46)



A BELT-SANDER
AT WORK
(*see* page 46)

DRILLING
IN
WOODWORK
(10–15 foot-candles : *see* page 48)

ELECTRIC
WELDING
(10–15 foot-candles : *see* page 48)

CUTTING METAL
WITH A
GUILLOTINE

(10–15 foot-candles :
see page 48)

A METAL TURNER
AT HIS LATHE

(15–20 foot-candles :
see page 49)

OVEN CONTROL
AT A
BAKERY

(10–15 foot-candles :
see page 46)

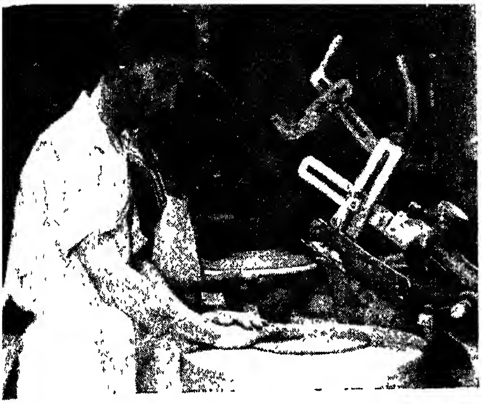
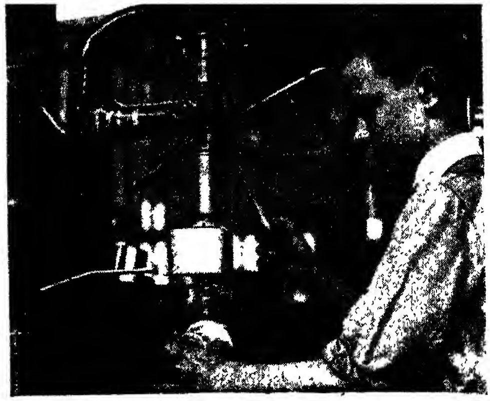


PLATE-MAKING
AT A
POTTERY
(10–15 foot-candles :
see page 50)

PLATING
METAL
(8–12 foot-candles :
see page 50)

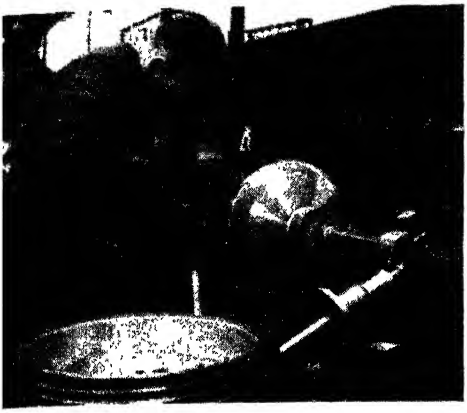
POLISHING
METAL
AT AN
ENGINEERING
WORKS
(12–20 foot-candles :
see page 50)



DRILLING
IN
METAL
(12–20 foot-candles :
see page 48)

OPERATING
AN
ENGINEER'S PRESS
(10–15 foot-candles :
see page 50)

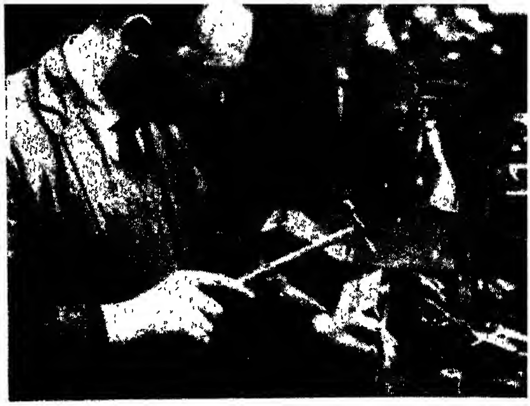
OPERATING
A
LAUNDRY PRESS
(12–20 foot-candles :
see page 50)



SPINNING AT AN ENGINEERING WORKS
(15–20 foot-candles : *see* page 51)

SPRAYING WOODWORK
(15–25 foot-candles : *see* page 51)

STEEL ROLLING AT A STEEL-MILL
(8–12 foot-candles : *see* page 51)



IN THE TOOL-SHOP
(20–30 foot-candles : *see* page 52)

WORKING IN MARVER IN A GLASSWORKS
(10–15 foot-candles : *see* page 52)

WEAVING IN A COTTON-MILL
(15–25 foot-candles : *see* page 52)

HEAT AND PRESSURE OVENS (Glass): Light is required all round the crate as it is fed in for heat and pressure treatment. The gauges on the apparatus also need to be seen. (8–12 foot-candles.)

HEEL PARING (Leather): The operator needs to see right down to the point where the tool is working on the side of the heel to watch just how much is being taken off. (15–25 foot-candles.)

ICING CAKES: Good illumination on top and all round the cake is needed, especially where fine work such as this is done. The operator should not cast shadows. (15–25 foot-candles.)

INSPECTION (Woodwork): Good diffuse illumination is required with an absence of shadow so that all parts can be seen clearly. (15–20 foot-candles.)

IRONING: Diffuse lighting over the table will enable the operator to watch the work without being troubled by shadows cast by the iron itself. Artificial daylight is recommended for quicker detection of scorches. (15–25 foot-candles.)

LASTING (Leather): This rather complicated machine requires the lighting units carefully placed so that the light reaches the work without difficult shadows being thrown on it by any apparatus. (15–25 foot-candles.)

LATEX DIPPING (Rubber): There must be light to enable the articles to be inserted carefully, not against the side of the vat, and for the surface of the liquid to be kept clean. (10–15 foot-candles.)

LATHE (Engineering): The operator has to watch the work as he feeds the tool. The light is also needed on the face of the chuck without causing reflected glare or shadow from the worker. (15–20 foot-candles.)

LINOTYPE: Lighting is required on the operator's copy and on the keyboard. It is also needed where the matrices are delivered to enable him to justify it before casting. (20–25 foot-candles.)

LOADING KILN TRUCKS (Pottery): General illumination is required all round the trucks as the saggars are piled up in them so that it is easy to see they are placed securely. (6–10 foot-candles.)

LOOM: The operator is tracing a broken end and she needs to see in among a great many obstructions. It is only by very good diffusion and suitable contrasts that she can have sufficient visibility to do this readily. (20–35 foot-candles.)

LOOM WARPING: Light is required down each alley to enable the ends to be drawn in correctly and to be found easily when a break occurs. (12–20 foot-candles.)

MENDING (Wool): Light is needed on the cloth, first to find the point needing repair, and then to do the sewing. If the cloth is dark there is need for higher values of illumination. (20–50 foot-candles.)

MIXING (Food): Preparation of the mixture requires a diffused light which will not only avoid shadows on the tables, but will also penetrate well inside the bowls. (10–12 foot-candles.)

MONO-CASTER: Good diffused lighting is required in this department to enable the controls to be seen, the type to be watched as produced and the matrices to be changed as required. (15–25 foot-candles.)

MONOTYPE KEYBOARD: Light is needed principally on the copy, but also, of course, on the keyboard. The operator's shadow must not be cast on these parts. (15–25 foot-candles.)

MULE SPINNING (Wool): Light is needed for the operator to watch for broken ends and to be able to find them when they drop so that they can easily be joined. (12–20 foot-candles.)

Order Charts (Food): Light is needed on the vertical surface of charts such as these to enable the worker to find the items easily. (10–20 foot-candles.)

Oven Control (Food): All the array of controls and dials over this vertical surface need to be clearly illuminated and light should penetrate the inspection chamber. (10–15 foot-candles.)

Packing: A good general light free from shadows enabling the packer to handle articles and wrapping paper without waste or fear of damage. (8–12 foot-candles.)

Paper Pulping: General lighting which avoids throwing shadows from the machine and lights up the aperture into which material is fed. (6–10 foot-candles.)

Paper Rolling: The light is wanted between the banks of rollers so that the operator can watch the material passing through. Light should come from the sides of the machine, not from the ends where it would throw shadows. Supplementary lighting is generally necessary. (10–15 foot-candles.)

Perching (Wool): Often it is an advantage in showing up faults to light from behind the cloth, in which case the light source should appear as even as possible across the width of it. Light is wanted on the vertical surface of the cloth as it is examined.

Pill Wrapping: Light is wanted on the tongue of the machine where the paper is folded round the pill. (10–15 foot-candles.)

Planing (Engineering): Light is needed on the work where the tool is travelling without throwing a shadow from it. (15–20 foot-candles.)

Plate-making (Pottery): Light is required evenly on the whole wheel so that no shadows are cast and the operator can readily see how the clay is forming. (10–15 foot-candles.)

Platen Press: Light is needed for the operator to see clearly as he feeds the sheets into the press and removes them. He needs to see to place them correctly and to watch the printing. (15–25 foot-candles.)

Plating: The workers need to be able to see into the vats and baths and the light should penetrate these. The lighting fittings should be suitable to resist the fumes. (8–12 foot-candles.)

Polishing (Engineering): Light is wanted on spindle end and mop especially where it is nearest the operator—also on the work as it is withdrawn to see the effect. Enclosed type fittings are recommended on account of the dirt. (12–20 foot-candles.)

Pottery Printing: The operator needs light on his press under the cylinder and on the benches where the actual goods are handled. (10–15 foot-candles.)

Press (Engineering): The light is wanted right inside the press where the blank is placed in position, and it should, as far as possible, be free from reflected glare. Usually supplementary lighting has to be employed. (10–15 foot-candles.)

Press (Printing): On the various types of presses the minders need good illumination to watch the sheets as they come off the machines for inking, register, etc. Light is also needed on the various controls and on the type for adjustment. (15-25 foot-candles.)

Presses (Laundry): It is necessary for the light to reach the lower part of the press, avoiding both the raised upper portion and the operator, so that no shadows impede the working. (12-20 foot-candles.)

Process Engraving: For this fine work good levels of illumination are

necessary, and at the same time shadow must be avoided from the operator's hand, and bright spots focused by his glass should not be present. (25–50 foot-candles.)

PROOFING: Light is needed on the bed where type or blocks are placed and for the operator to examine the result. (15–25 foot-candles.)

RING SPINNING (Cotton): The operator needs to watch for broken ends all along both sides of the gate and the light needs to be arranged not to throw shadows besides showing up clearly all the threads, and to reach well down to the cops. (20–30 foot-candles.)

ROVING (Cotton): The light needs to penetrate into the machine so that the operator can see to find and mend any broken ends. (12–20 foot-candles.)

SAND-PAPERING BY HAND: Good diffused lighting is needed to see the work from various angles, but the results can best be seen against an illuminated matt white surface. Visor glass fronts should be used. (10–20 foot-candles.)

SCOURING (Pottery): Light is wanted on the bench so that the operator can readily handle the piles of articles to be dealt with and can see clearly the finish obtained on each piece. (10–15 foot-candles.)

SLUBBING (Cotton): Light is required over the tops of the machines where the operators have to watch the operation and to penetrate to the bobbins below. (15–25 foot-candles.)

SOAP CUTTING: Even light is needed over the table as the soap is moved about and cut. (8–12 foot-candles.)

SOAP WRAPPING: The light is needed along the bench on both sides of the conveyor so that no shadows are thrown by workers, goods, or by the overhead rack. (10–12 foot-candles.)

SOLE ATTACHING: It is necessary to be able to see clearly the position of the tool and the light must clear the actual operators and apparatus. (15–25 foot-candles.)

SORTING (Laundry): Light is required both to enable the operator to see the marking and to see into the shelves or racks where the articles are placed. It should be diffused sufficiently to avoid shadows and undue reflections. (15–25 foot-candles.)

SORTING (Paper): Good lighting of a diffused character is necessary to enable the surface of the sheets to be distinguished easily and quickly, and to avoid reflected glare. (15-25 foot-candles.)

SPINNING (Engineering): The spinner needs to see the metal on the chuck fairly low down where he is working it, but without reflected glare. (15–20 foot-candles.)

SPRAYING (Woodwork): Light is wanted on the turntable and should be arranged so that no shadow is thrown by the operator. Protected fittings should be used. (15–25 foot-candles.)

STAINING (Woodwork): Diffused lighting to avoid areas being overshadowed and best visibility is obtained by means of controlled reflections which reveal coverage. (15–20 foot-candles.)

STEEL ROLLING: Light is required to clear overhanging structures to ensure safety when the hot billets are being handled. (8–12 foot-candles.)

STEREO FINISHING: A good value of illumination is necessary on the stone to enable the operator to see the necessary detail clearly. (20–50 foot-candles.)

STORAGE RACKS (Food): The light is needed to penetrate right into each shelf up the vertical face of the rack.

STORES (Woodwork): The high stacks of wood cause obstruction and shadow unless the lighting is arranged to light between them. (5–10 foot-candles.)

TESTING (Rubber): Testing by inflation requires light along the bench to enable easy handling of the goods and to keep the benches clean. (8–12 foot-candles.)

TESTING PISTON HEADS: For the careful measurement necessary there must be light on the parts being examined and on the dials of instruments. Micrometer testing requires further special consideration of the lighting. (15–25 foot-candles.)

TOOL SHOP: The tool shop is a vital part of a works to-day, and good lighting is essential to enable the necessary high degree of accuracy to be maintained. (20–50 foot-candles.)

TRANSFER (Pottery): It is necessary first to see clearly to cut out the transfers from the sheet and then to be able to set them accurately in position. (12–20 foot-candles.)

TYPE-SETTING BY HAND: Light is needed well diffused over the cases sothat the type-setter can see his copy and the type, and can see to justify it afterwards. (20–50 foot-candles.)

UPHOLSTERY (Motor): The inside of the car needs to be illuminated to enable the worker to see the detail of the work he is handling. (15–25 foot-candles.)

VATS (Soap): The operator needs some light over the top of the vat to see the state of the liquid and on the controls at the side. Enclosed fittings should be used. (8–12 foot-candles.)

WAREHOUSE (Glass): Light must penetrate into the racks where glass is stacked and is needed well diffused over the tables where it is cut or, as shown here, examined for accurate bending. (8–15 foot-candles.)

WAREHOUSE (Pottery): The stacks of articles on the floor and in racks require the light distributed evenly over the horizontal plane as operatives sit promiscuously. The floor is the working level. (8–12 foot-candles.)

WARPING (Wool): The operator needs to watch for broken ends so that a good diffused light is needed to enable them to be traced and joined. (15–25 foot-candles.)

WARPING FRAME (Cotton): The back of the frame shown here needs good diffused lighting to enable the ends to be picked out and the machine to be set up expeditiously. (12–20 foot-candles.)

WEAVING (Cotton): Good diffused lighting is required over the front and back of the machine to enable the operator to see and repair broken ends. (15–25 foot-candles.)

WEIGHING (Food): The operator needs to watch the material he is putting on the scales and the dial must be clearly illuminated so that it can be read accurately and quickly. (10–15 foot-candles.)

WOOL COMBING (French Process): The operator needs to see all the feeds and the wool as it passes through the machine, and particularly the last part of its journey. (10–20 foot-candles.)

WOOL CUTTING: The operator needs to see where the cloth is coming through the machine and from where he stands there should not be shadows on it. Visor glass fronts are recommended. (8–15 foot-candles.)

WORKING IN MARVER (Glass): The worker needs to be able to see the shape of the metal as it grows and to see that it is fitting the size and shape of the marver. (10–15 foot-candles.)

WRAPPING: Lighting is wanted on the benches to enable the packages

to be wrapped without awkward shadows and the stacks of packages should not obscure the light. (10–15 foot-candles.)

WRAPPING AND BOXING: The light is required on the benches with no shadows from either operatives or the stacks of boxed articles. (10–15 foot-candles.)

CHAPTER EIGHT

DESIGN OF LIGHTING INSTALLATIONS

LIGHTING installations must be scientifically planned if the best results for money spent are to be obtained. Factory Department requirements are much higher than they were formerly, and old standards of design must be consigned to oblivion. Modern methods of design accurately predict the effect produced by any given combination of lamps and fittings. The selection and spacing of lighting units, the coefficient of utilization, depreciation and other factors which influence the result must be handled with scientific care. Rule-of-thumb methods have been discarded. Accurate data is now available in the form of charts and tables by which the illumination of any industrial interior may be quickly calculated with the sure knowledge that results will be effective.

The fundamental considerations in laying out an installation are:

1. Foot-candle illumination required on the working plane. See Appendices, pages 103 to 109.
2. Selection of type of lighting unit most suitable for the industry concerned.
3. Deciding layout of points, mounting height and number of lighting units.
4. Ascertaining the lamp size which will provide the foot-candle intensity required.

1. Foot-candle illumination required:

The amount of illumination and the various factors influencing this have been dealt with in previous chapters and the table on pages 103 to 109, gives the range of illumination values that are considered desirable for different classes of work. These values are based upon practice established through years of experience.

Persons of advanced years or with defective eyesight require more light than do those having perfect vision. A range of foot-candle values is given for each group of operations; in modern practice it will usually be found desirable to select values in or even beyond the upper portion of the range.

It is recognized that any specified process when carried on in different factories is performed with different degrees of fineness, and with other variations; so that one factory may need more illumination than another for the same class of work. In the table, ranges of foot-candle values are given to correspond to the variations actually existing in practice.

Attention is drawn to the fact that the values in the table are *operating values*; that is, they apply to measurements of the lighting system in ordinary use, not simply when the lamps are new and clean.

It must be realized that a new lighting installation will inevitably lose

some of its initial efficiency in service owing to the deterioration of reflecting properties of fittings, walls and ceiling, and to dirt on the lamps. When planning a lighting system it is therefore necessary to make some allowance for these facts, and since it is reasonable to expect the efficiency of the original installation to fall some 30 per cent. in service it should be designed so as to provide initially an illumination 1·43 times as much as the amount required in service. This factor does not make allowance for insufficient cleaning by the maintenance staff.

Where the higher levels are specified for particular processes such illumination need not be supplied for all parts of a workshop, nor on all parts of a machine, but only at places where work of the type indicated is likely to be performed. Thus, in a workshop, a general illumination providing the value specified for passageways or storage spaces might be supplemented at proper positions by higher illumination specified for work of different degrees of fineness in the table. The high illumination may be required over small areas only, as in watchmaking and machine sewing, or over wide areas.

In practice, the lower values required in the workshop will often be considerably exceeded in order to conveniently provide for the higher values. This is fortunate since it avoids the possibility of having extreme contrasts between the actual working area and the surroundings.

It may be difficult to obtain the exact illumination aimed at owing to the fact that lamps are only obtainable in certain standard sizes.

2. Choosing the lighting unit:

The second step in the design of interior lighting installations is to choose the most suitable type of fitting. The selection of the most desirable type of unit depends not only upon the requirements of the work, but in some cases upon the construction of the room and the colour of ceiling and walls. For example, semi- and totally indirect lighting is unsuited to rooms with very dark ceilings. But the final choice will probably depend on a compromise, giving due weight to the effects of glare, shadows, distribution and diffusion desired from, and possessed by, the fitting in question. The Index of Reflector Types shown on page 57 gives the principal types of fittings used in industry, together with the notes as to their suitability for different conditions. This is the result of many years of practical experience. They are classified in accordance with the way in which they control the light.

Industrial general lighting is usually of the direct-lighting small-area type. This can be defined as a lighting system in which practically all (90 to 100 per cent.) of the light of the fittings is directed in angles below the horizontal, i.e., directly towards the usual working areas. While, in general, such systems provide illumination on the workers' surfaces most efficiently, this may be at the expense of other factors, such as excessive contrasts of the light source with the surroundings, troublesome shadows, and reflected glare. Care should be taken to instal the equipment to avoid exposing the workers' eyes to the glare from brilliant lamps, filaments or excessive contrasts between the light source and its background.

There are two different types of equipment usually classified under this heading—distributing types and concentrating types. The distributing types are units such as porcelain-enamelled reflectors, porcelain-enamelled diffusers, aluminium, mirrored or prismatic-glass industrial fittings. As the name implies, these units distribute the light over a wide area and

provide uniform illumination when spaced approximately equal to the mounting height above the floor. In no case should the angle of the cut-off of light be less than 15 degrees below the horizontal and a somewhat lower cut-off is desirable.

Among the concentrating direct-lighting types are prismatic and mirrored glass and aluminium industrial reflectors. These are used for narrow high bays and craneways where it is necessary to mount the reflector at a height as great or greater than the width of the area to be illuminated. In this case a concentrated beam is necessary in order to get the light to the working area without excessive loss on the walls. Spacing should be such as to provide uniform illumination over the working area. Such units are also frequently used in smaller sizes, some equipped with louvres, for the local lighting of specific work areas.

In the semi-direct lighting classification 60 to 90 per cent. of the output of the fitting is directed downwards to the working surface. There is, therefore, some contribution to the illumination at the working plane from light which is directed upwards and reflected by the ceiling and upper wall areas. For the most part fittings in this class are of the open bottom type, though some enclosing glass units are included. They are quite suitable for such areas as passages, stairs, wash-rooms, etc.

General diffused lighting in which 40 to 60 per cent. of the output is reflected downwards refers to systems where the predominant illumination on horizontal working surfaces comes directly from the lighting units, but where there is also a considerable contribution from upward light reflected back from ceiling and upper wall areas. For the most part at the present time these units are of the glass diffusing enclosing-globe type and are used in offices.

Diffusing glass globes should be of sufficient density to conceal completely the lamp inside ; they should be made of well-annealed glass that is not easily broken, and the hanger should be of good mechanical construction to grip the globe securely without chance of breakage. While a general diffused lighting system gives more illumination for a specified wattage than do indirect or semi-indirect systems, shadows are more noticeable, some difficulty may be experienced with both direct and reflected glare and in general the results are less satisfactory for office work. Other factors being equal, a higher mounting gives better illumination results.

Where it is desired to improve an existing general diffuse lighting system, a temporary expedient is the use of parchment shades which hang over the enclosing globe. The shades redirect much of the light, which is emitted in nearly horizontal angles, downwards, resulting in a considerable increase in utilization in smaller offices and lessened direct glare in large offices.

With semi-indirect lighting more than half the light is directed to the ceiling and upper walls, from which it is reflected diffusely to all parts of the room. Because the ceiling constitutes an important part of such a lighting system, careful attention must be paid to having it as light in colour as possible and to maintaining it in good condition. Fittings of this type are available in completely enclosed styles, which prevent the collection of dust and dirt and are easily cleaned.

The semi-direct lighting units present a lower-brightness to the eye and to the work than the general diffuse units, and in this form they are more suitable for factory offices.

With indirect lighting, 90 to 100 per cent. of the light from the fittings is first directed to the ceiling and upper walls from which it is reflected

diffusely to all parts of the workshop. In effect, the entire ceiling and high walls become a light source. With such a large area serving as a source of light little direct glare is experienced. Shadows are almost eliminated and reflected glare reduced. With many polished metal pieces, a maximum visibility is obtained of such things as ruled lines, figures, blemishes, which are seen against a polished background. However, because the ceiling constitutes an important part of such a light system, careful attention must be paid to having it as light in colour as possible and maintaining it in good condition. It should be given a matt white finish having a high reflection factor. Recently there have been developed specially configurated ceilings, semi-matt finished, that are designed to present reduced brightness at the angles at which they are normally seen. The lighting unit, which may have either opaque or luminous bottoms, should be such that they can easily be cleaned because a layer of dust and dirt forms and this absorbs a surprising amount of light.

Indirect lighting produces a quality of lighting best for offices. This quality of lighting is highly desirable for such visual jobs as are found in drawing offices, general and private offices.

Large-area sources of uniform brightness approximate indirect lighting in effect. One measure of the quality of lighting which a given source will produce is the angle subtended by the source of the point of work. With three-dimensional work jobs, particularly of a specular or semi-specular nature, this factor is of much importance. The most common large-area source is an indirect lighting system. However, there are many places in industry where indirect lighting is impracticable ; for such cases there are available types of units which produce somewhat the same lighting effect. They consist of large luminous areas, placed relatively close to the point of work. In this way the subtended angle is of the same order of magnitude as a ceiling lighted with indirect fittings. For many positions throughout the actual working areas, such large-area sources are recommended. They are also effective in some offices.

For severe visual tasks which require more illumination than can be supplied practically from the general lighting system, there are available a number of specially designed fittings which supplement the general lighting over a limited area. Such fittings usually have a highly concentrated distribution of light and are carefully designed to prevent glare. In this way the light is confined to the immediate work area and does not become a source of glare to anyone in the room. Where a diffusing source of low brightness is needed, a large-area, low-brightness unit can be placed directly over the work zone.

Local lighting fittings when concentrated should preferably be mounted at some distance from the point of work. In this way they cannot easily get out of adjustment, they are not in the way of the workman, and do not present a heat problem. However, in cases where a certain degree of adjustment is desirable, fittings are mounted on flexible arms for manipulation by the workman to obtain the maximum advantage.

3. Mounting height and spacing :

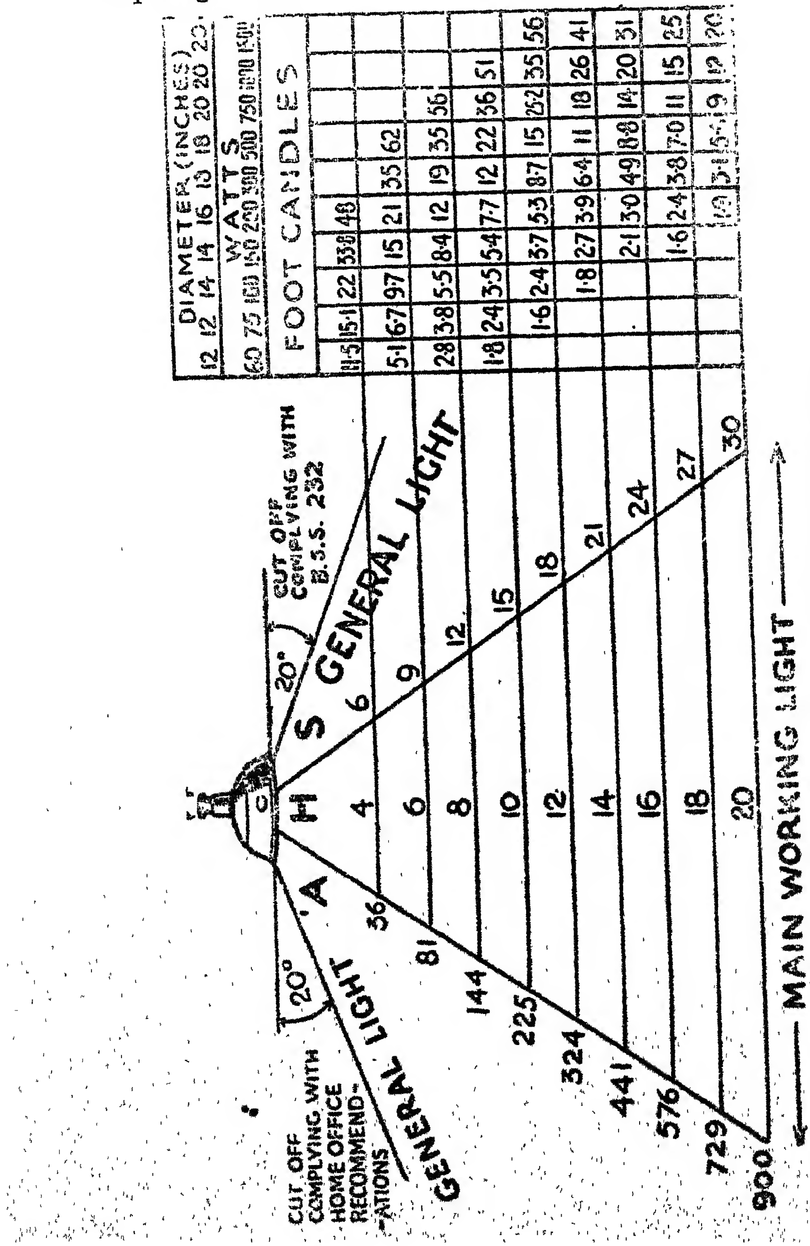
After the type of fitting most suited to the industry carried on in a particular shop has been settled, the next steps are to decide upon the height, spacing and position of points. The diagrams and tables shown on the following pages provide simple and reliable methods of calculation compiled by Messrs. Crompton Parkinson & Co., Ltd.

INDEX OF REFLECTOR TYPES

Type of Reflector.	Purpose.	Height Spacing ratio.	
		Mounting height.	Spacing.
DISPERSIVE .	Fulfils the requirements of the majority of industrial situations, providing adequate illumination in both horizontal and vertical planes . .	1	$1\frac{1}{2}$
CONCENTRATING .	For lofty buildings, or where concentrated illumination on the horizontal plane is desirable. Particularly suitable for mounting above overhead cranes, in combination with angle reflectors . .	1	1
VERTICAL ELLIPTICAL . .	For any situation where a wide distribution is necessary in one plane such as stores, gangways, workshop benches, etc. . . .	1	$1\frac{2}{3}$
ANGLE ELLIPTICAL	For similar situations as the parabolic type, but where wide spacings and shorter throws are required . .	1	$1\frac{1}{3}$
DIFFUSER . .	For the general lighting of workshops where fine or intricate work is performed calling for soft diffused lighting. Also for works offices and drawing offices which have no effective ceilings .	1	$1\frac{1}{2}$
LOCAL . .	For local lighting of machine tools, etc., where high intensities are needed at the point of work. The deep skirt protects the operator's eyes from glare . . .	—	—
PARABOLIC ANGLE	For the illumination of vertical faces and for side lighting in workshops, etc., either alone or in combination with vertical type reflectors . .	1	1
DISTRIBUTING .	For area lighting employing wide spacings, and where illumination is required at a maximum height in the vertical plane . . .	1	2

R.L.M. Dispersive Reflector

Temperature of cables conforms with I.E.E. regulations.
A. Area per point in square feet.
H. Height above plane of work in feet.
S. Spacing in feet.



H	A	S	DIAMETER (INCHES) 12 / WATTS 60	12 / 75	14 / 100	14 / 150	16 / 200	18 / 300	18 / 500	20 / 750	20 / 1000	20 / 1500
			FOOT CANDLES									
4	36	6	11·5	15·1	22	33·8	48					
6	81	9	5·1	6·7	9·7	15	21	35	62			
8	144	12	2·8	3·8	5·5	8·4	12	19	35	56		
10	225	15	1·8	2·4	3·5	5·4	7·7	12	22	36	51	
12	324	18		1·6	2·4	3·7	5·3	8·7	15	25·2	35	56
14	441	21			1·8	2·7	3·9	6·4	11	18	26	41
16	576	24				2·1	3·0	4·9	8·8	14	20	31
18	729	27				1·6	2·4	3·8	7·0	11	15	25
20	900	30					1·9	3·1	5·4	9	12	20

Fig. 7.—R.L.M. Dispersive Reflector

LIGHT DISTRIBUTION

R.L.M. dispersive reflectors are made in accordance with British Standard Specification No. 232, which, *inter alia,* covers the angle of cut-off and efficient light distribution. The optical contour is a combination of concave and cylindrical reflecting surfaces forming a widely dispersive reflector.

The main distribution of light is obtained up to 65 degrees from the vertical. View of filament is cut off at 70 degrees. The maximum light intensities are obtained from the vertical up to 45 degrees. Uniform illumination is thus obtained with a spacing of one and a half times the height of lamp filament above the plane of work.

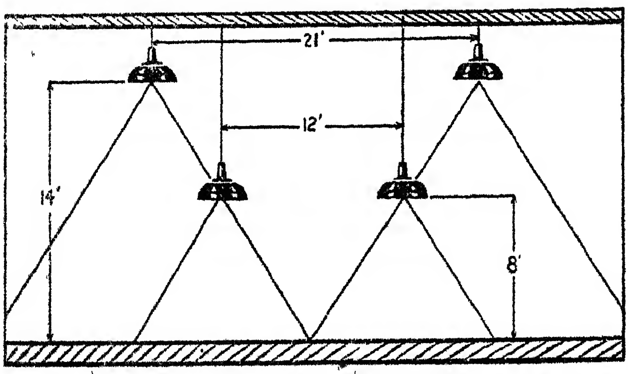


FIG. 8.—DISTRIBUTION OF LIGHT WITH DISPERSIVE REFLECTORS

Example

Given (A): The illumination required in foot-candles—12.

Given (B): The available height from floor to ceiling—12 ft.

(1) Take the height of plane of work (say 3 feet) plus height of fitting (say 1 foot) from height, floor to ceiling, e.g. 12 feet − 4 feet = 8 feet, being height of lamp above plane of work (H).

(2) Find height above plane, 8 feet, under H in the centre of triangle.

(3) Trace horizontal line to right when the spacing 12 feet is found at the edge of triangle.

(4) Continuing along to the table on right till 12 foot-candles is found.

(5) Look up to head of column where lamp wattage 200 and reflector diameter 16 inches is given.

(6) If required the area per point 144 square feet is found on left of triangle.

Concentrating Reflector

A. Area per point in feet.
H. Height above plane of work in feet.
S. Spacing in feet.

A	H	S	Diameter (ins) 9, Watts 60	9, 75	12, 100	12, 150	15, 200	15, 300	18, 500	18, 750	18, 1000	18, 1500
			Foot candles									
81	9	9	4·6	6·1	8·9	13	19	32	57			
121	11	11	3·1	4·1	5·9	9·2	13	21	38	61		
169	13	13	2·2	2·9	4·3	6·6	9·4	15	27	44		
225	15	15	1·6	2·2	3·2	4·9	7·0	11	20	33	46	
289	17	17	1·3	1·7	2·5	3·8	5·5	8·9	16	25	36	57
361	19	19			2·0	3·0	4·4	7·1	12	20	29	46
441	21	21			1·6	2·5	3·6	5·8	10	16	23	37
529	23	23				2·1	3·0	4·9	8·8	14	19	31
625	25	25				1·7	2·5	4·1	7·4	11·8	16	26
729	27	27				1·5	2·1	3·5	6·4	10	14	22
841	29	29					1·9	3·0	5·5	8·9	12	19
961	31	31					1·6	2·7	4·8	7·7	10·9	17
1089	33	33					1·4	2·3	4·2	6·8	9·6	15
1225	35	35						2·1	3·8	6·1	8·5	15
1369	37	37						1·8	3·4	5·4	7·6	12

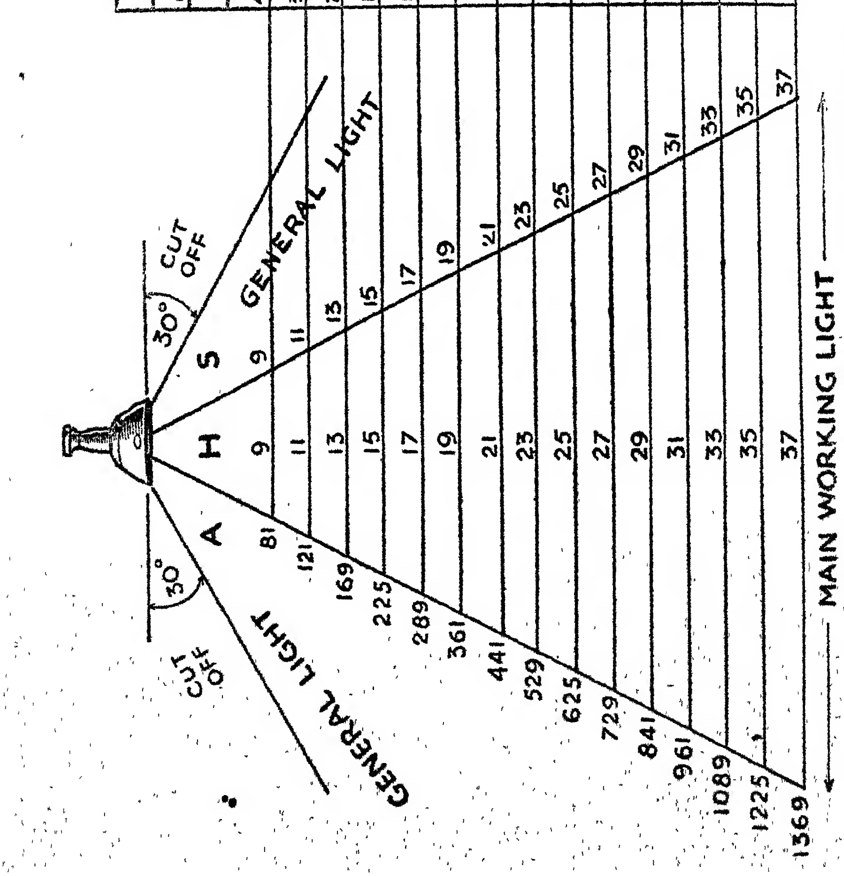


Fig. 9.—Concentrating Reflector

LIGHT DISTRIBUTION

In the Concentrating Reflector the optical contour of the reflecting surface is designed in the form of a deep parabola, the axis being vertical and coinciding with the centre of the light source. The main distribution of light is obtained up to 45 degrees from the vertical. View of the filament is cut off at 60 degrees. The maximum light intensities are obtained from the vertical up to 25 degrees. Uniform illumination is thus obtained with a spacing equal to the height of lamp filament above plane of work.

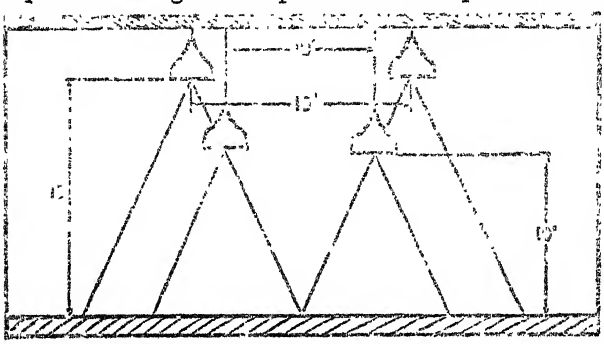


Fig. 10.—DISTRIBUTION OF LIGHT WITH CONCENTRATING REFLECTORS

Vertical Elliptical Reflectors

APPLICATION

Spacing along an area one and two-third times the height above the plane of work, vertical elliptical reflectors are used for adequate illumination in positions where the area to be lighted is long in proportion to its width. They are ideal for lighting gangways between warehouse bins, and benches placed along walls which cannot be economically lighted with circular dispersive reflectors.

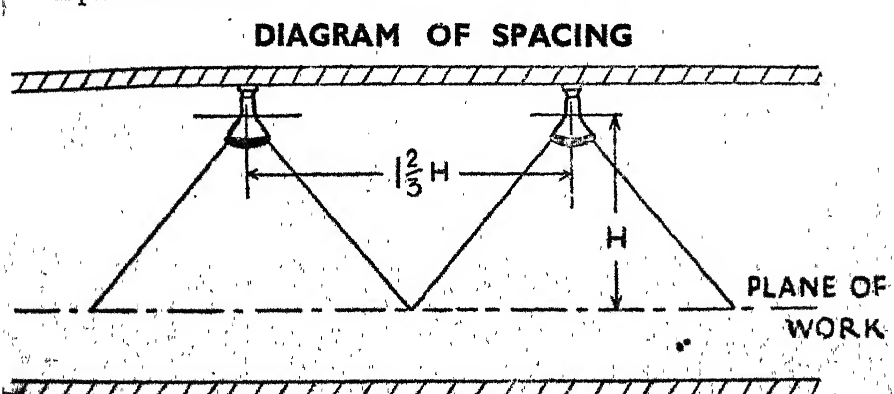


Fig. 11.—LONGITUDINAL SPACING OF VERTICAL ELLIPTICAL REFLECTORS

Vertical Elliptical Reflectors

LIGHT DISTRIBUTION

The angle of cut-off through the major axis of the fitting is 63 degrees from the vertical, while that across the fitting is 44 degrees. These figures are considerably better than the 70 degrees cut-off recommended by the

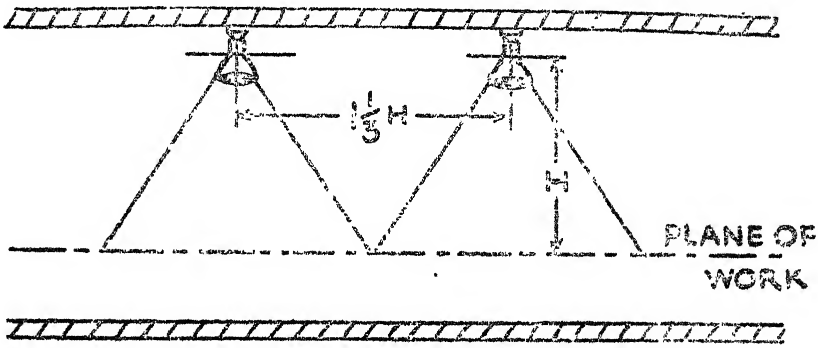


Fig. 12.—LATITUDINAL SPACING OF VERTICAL ELLIPTICAL REFLECTORS

Factory Department, and therefore the unit is admirably suited to such positions as bench lighting, where the lighting fittings are close to the workers. The ratio of the length to the width of the area lighted by one fitting is $1\frac{1}{3}$ to 1, while the spacing along the area is $1\frac{2}{3}$ times height above plane of work.

Angle Elliptical Reflectors

LIGHT DISTRIBUTION

Elliptical Angle Reflectors are designed to project the light forward in the vertical plane and at the same time spread it laterally to increase the permissible spacing for uniform illumination. The main distribution through minor axis—all angles being measured from the vertical—is from 5 degrees behind the reflector to 75 degrees in front, the maximum light intensities being from 25 degrees to 55 degrees in front of the reflector. The view of the filament is cut off at 14 degrees behind the reflector and 74 degrees in front. The cut-off sideways is 53 degrees.

Mounting Data. Elliptical Angle Reflectors, when used for lighting vertical surfaces, or for side-illumination in a works, should be mounted in accordance with the data given in the tables and diagrams below and opposite.

Ratios for lighting from the sides of workshops, etc. (see Fig. 13).

Table 1

Height above working plane	A
Distance from wall effectively lighted	A
Spacing between reflectors	A

When these reflectors are used at the sides of a workshop they provide a scheme (with overhead Concentrating or R.L.M. Reflectors) which is practically independent of the colour of the walls and ceiling for efficiency. This is due to the light being directed away from the walls. In addition, such a

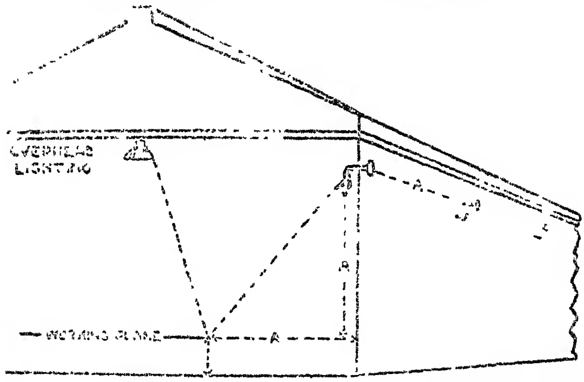


FIG. 13.—RATIOS FOR LIGHTING FROM SIDES OF WORKSHOPS

scheme in high narrow bays ensures adequate light on vertical surfaces. Elliptical Angle Reflectors are used in preference to the Parabolic Angle type where the light is required to be widespread sideways and not above 65 degrees from the vertical. The Elliptical Angle Reflector has a 37 degrees cut-off sideways, and therefore complies with Factory Department recommendations.

ANGLE ELLIPTICAL REFLECTORS

Ratios for lighting vertical surfaces (see Fig. 14).

Table 2

Height of surface	A
Projection from surface	A
Spacing from end of surface	$\frac{3}{4}$A
Spacing distance between Reflectors . . .	$1\frac{1}{2}$A
Height of bottom of Reflector above top of surface	$\frac{1}{4}$A

With height of the surface given in Column X, the average illumination is 10 foot-candles with diversity 2 : 1 ; i.e. maximum illumination does not exceed twice minimum. If, however, to reduce projection, the height of the surface is taken from column Y, the illumination of the lower part of the surface will be considerably reduced, making the average 5·5 foot-candles and the diversity 5 : 1. The above data is calculated on the use of at least three reflectors. The neck of the reflector is vertical in each case, no tilt inward being necessary, due to the reflector being mounted above the top of the surface

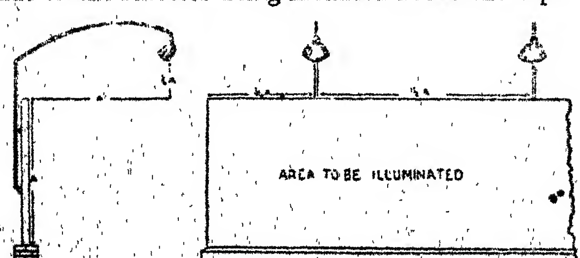


FIG. 14.—RATIOS FOR LIGHTING VERTICAL SURFACES

Lamps Recommended.	Height of Surface.		Distance Out.	Spacing.		Height above Top.
	X	Y		From Ends.	Apart.	
	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.	ft. in.
60 watts	3 0	4 10	3 0	2 3	4 6	0 9
100 ,,	4 0	7 0	4 0	3 0	6 0	1 0
150 ,,	5 0	8 9	5 0	3 9	7 6	1 3
200 ,,	6 0	10 6	6 0	4 6	9 0	1 6
300 ,,	7 6	13 0	7 6	5 7	11 3	1 9
500 ,,	10 0	17 6	10 0	7 6	15 0	2 6

Diffusers

A. Area per point in square feet.
H. Height above plane of work in feet.
S. Spacing in feet.

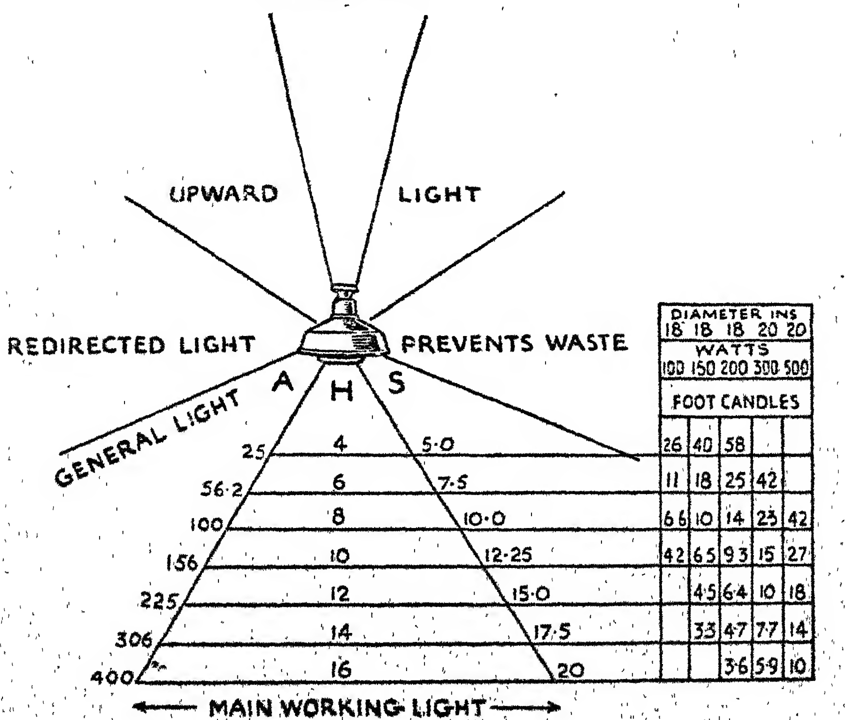


Fig. 15.—Diffusers

LIGHT DISTRIBUTION

The main light distribution—all angles being measured from the downward vertical—is from 0 degrees to 65 degrees. Maximum intensities from 0 degrees to 45 degrees. Thus uniform illumination is obtained with a spacing ratio of $1\frac{1}{4}:1$. There is an upward component of 105 degrees to 180 degrees, which comes both through the diffusing globe and through apertures in the upper part of the vitreous enamelled reflector. This component provides a proportion of illumination for ceiling lighting.

When the Daylight Diffuser is used the foot-candle values shown in the chart opposite should be reduced by about 40 per cent. Higher wattage lamps, therefore, or more points are necessary for this class of lighting.

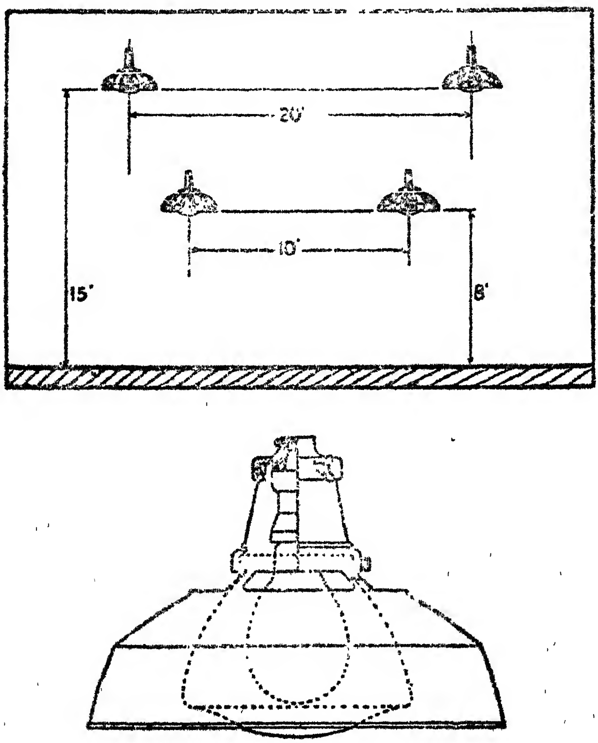


FIG. 16.—LIGHT DISTRIBUTION WITH DIFFUSERS

LOCAL LIGHTING REFLECTORS

EXTENSIVE TYPE

LIGHT DISTRIBUTION. The deep bowl reflector is in the form of a hyperbolic curve decentred relatively to the vertical axis of the reflector. The

characteristic light distribution of this supplementary local lighting reflector is such that the maximum light intensity is obtained in angles from 0 degrees to 45 degrees, while the actual angle of cut-off is 58 degrees from the vertical.

SPACING AND MOUNTING DATA

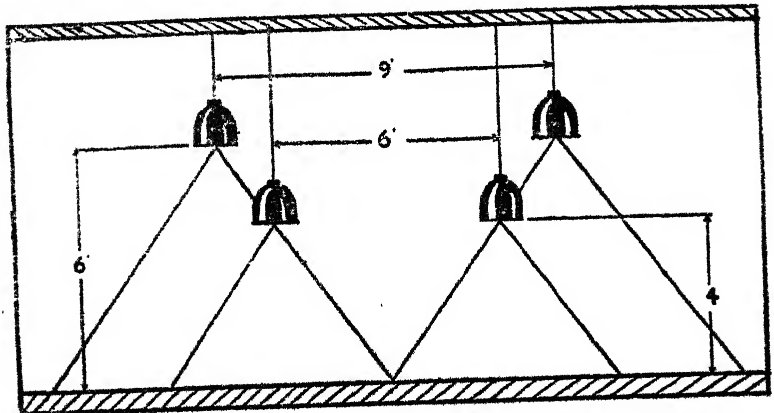


FIG. 17.—SPACING AND MOUNTING DATA FOR EXTENSIVE TYPE OF LOCAL LIGHTING REFLECTOR

Maximum Spacing Distance.	Mounting Height above Bench.
4ft. 6in.	3ft. 0in.
5ft. 3in.	3ft. 6in.
6ft. 0in.	4ft. 0in.
6ft. 9in.	4ft. 6in.
7ft. 6in.	5ft. 0in.

LOCAL LIGHTING REFLECTORS

INTENSIVE TYPE

LIGHT DISTRIBUTION. The contour of the intensive type is a combination of convex and concave spherical curves. The characteristic light distribution is such that the maximum light intensities are obtained in angles from 0 degrees to 35 degrees, while the actual angle of cut-off is 58 degrees from vertical.

SPACING AND MOUNTING DATA

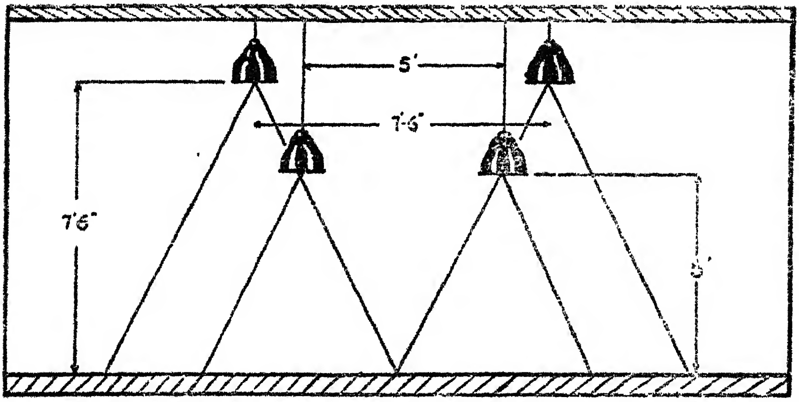


FIG. 18.—SPACING AND MOUNTING DATA FOR INTENSIVE TYPE OF LOCAL LIGHTING REFLECTOR

Maximum Spacing Distance.	Mounting Height above Bench.
3ft. 0in.	3ft. 0in.
3ft. 6in.	3ft. 6in.
4ft. 0in.	4ft. 0in.
4ft. 6in.	4ft. 6in.
5ft. 0in.	5ft. 0in.

PARABOLIC ANGLE REFLECTORS

LIGHT DISTRIBUTION. The optical contour of the Parabolic Angle Reflector is designed in the form of a deep parabola with the principal axis tilted at an angle of 45 degrees to the vertical. The characteristics of the Parabolic Angle Reflector are such that the main distribution of light (all angles being measured from downward vertical) is obtained from 0 degrees to 90 degrees in front of the reflector. Maximum light intensities are obtained from 15 degrees to 75 degrees in front of the reflector. The view of filament is cut off at 17 degrees behind and 84 degrees in front.

Parabolic Angle Reflectors

Mounting Data. The Parabolic Angle Reflector, when employed for the lighting of vertical surfaces, should be mounted in accordance with the data given in the sketch and tables shown on this and the opposite page.

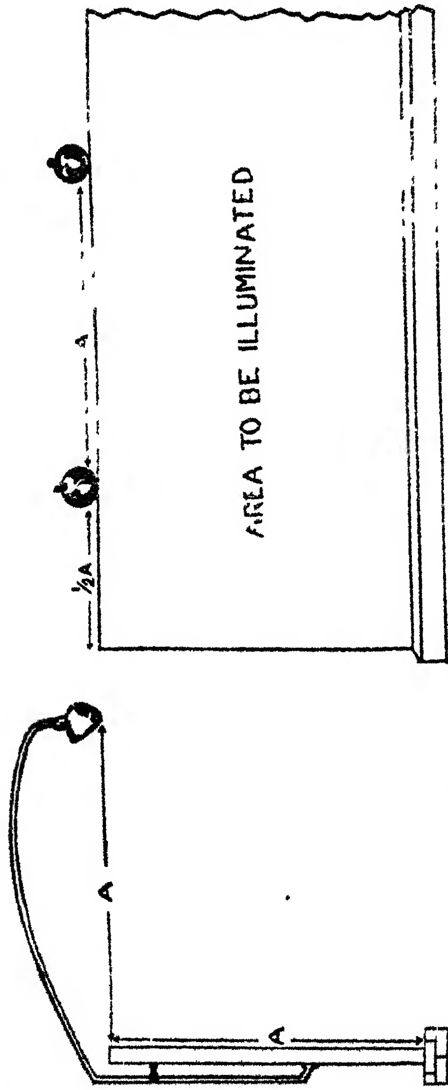


Fig. 19.-- Parabolic Angle Reflectors

Mounting Details for Vertical Surfaces. With height of surface given in column X, the average illumination is 10 foot-candles with diversity 2:1; i.e. maximum illumination does not exceed twice the minimum. If,

however, to reduce projection, the height of the surface is taken from column Y, the illumination on the lower part of the surface will be considerably reduced, making the average illumination 6·5 foot-candles, and the diversity 5 : 1.

The above data is calculated on the use of at least three reflectors.

Lamps Recommended.	Height of Surface.		Distance Out.	Spacing.	
	X	Y		From Ends.	Apart.
60 watts	3ft. 0in.	4ft. 6in.	3ft. 0in.	1ft. 6in.	3ft. 0in.
100 ,,	5ft. 0in.	7ft. 6in.	5ft. 0in.	2ft. 6in.	5ft. 0in.
150 ,,	6ft. 0in.	9ft. 0in.	6ft. 0in.	3ft. 0in.	6ft. 0in.
200 ,,	7ft. 3in.	11ft. 0in.	7ft. 3in.	3ft. 10in.	7ft. 3in.
300 ,,	9ft. 0in.	13ft. 6in.	9ft. 0in.	4ft. 6in.	9ft. 0in.
500 ,,	12ft. 3in.	18ft. 6in.	12ft. 3in.	6ft. 1in.	12ft. 3in.
750 ,,	15ft. 9in.	23ft. 6in.	15ft. 9in.	7ft. 10in.	15ft. 9in.
1,000 ,,	18ft. 6in.	27ft. 9in.	18ft. 6in.	9ft. 3in.	18ft. 6in.
1,500 ,,	23ft. 3in.	35ft. 0in.	23ft. 3in.	11ft. 7in.	23ft. 3in.

Distributing Reflectors

Application. Spacing $1\frac{1}{2}$ times the height above the plane of work. Distributing reflectors are used in positions where light is required sideways up to a height level with that of the reflector, e.g. gangways in warehouses, etc. These reflectors are also extensively used where a wide distribution of light is required.

Light Distribution. The design is based on the form of a double ellipse with the light source filament position placed at the juncture of the combined foci, thus forming a very efficient optical combination. The main distribution is obtained up to 90 degrees from the vertical. The maximum light intensities are obtained from the vertical up to 55 degrees. This allows a spacing of $1\frac{1}{2}$ times the height of the lamp filament above plane of work.

Spacing and Mounting Data

Maximum Spacing Distance.	Mounting Height above Working Plane (usually 3ft. above floor).
18ft.	12ft.
24ft.	16ft.
30ft.	20ft.
36ft.	24ft.

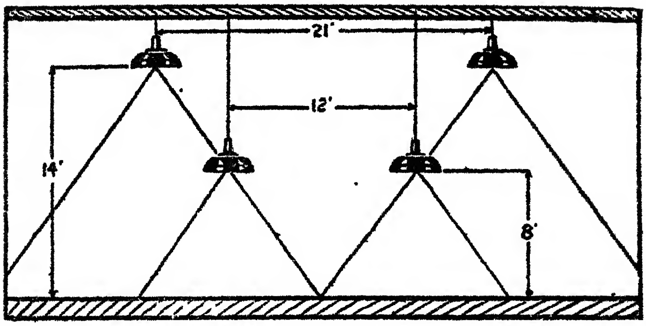


FIG. 20.—SPACING AND MOUNTING DATA FOR DISTRIBUTING REFLECTORS

The Electric Lamp Manufacturers' Association of Great Britain give the following method of calculating mounting height, spacing and position of fittings in industrial interiors.

Generally speaking, the approximate mounting height will usually be clearly indicated by the physical properties of the building, but it is usually considered undesirable to mount fittings less than ten feet above the floor as a low mounting height requires close spacing of fittings and consequently increases installation costs. From the economical point of view it is wise to mount the fittings as high as is reasonable.

Illuminating engineers are familiar with the 'inverse square law' which says that the illumination received on a surface is inversely proportional to the square of the distance of the light source from that surface; and while the law is perfectly true for a single point source of light, it by no means holds good where the installation consists of many lamps each of which is used with some kind of fitting in a normal room. Under these conditions an increase in the mounting height has only slight effect on the resulting illumination.

In practice, therefore, in a multi-storey factory it is usual to mount the fittings as close as possible to the ceiling; in a single-storey factory of medium height mount them at a sufficient height to avoid all moving machinery.

Having determined a suitable mounting height, it is then necessary to decide the spacing of fittings. Uniform illumination, minimum 6 foot-candles, is required over the whole working area—if fittings are too far apart there will be pools of light beneath them with comparative darkness in between. When the fittings are correctly placed, the light from any one fitting will overlap that received from adjacent fittings so that the illumination on the working plane at a point midway between fittings is only slightly less, or may be in some cases slightly more, than that immediately beneath the fittings.

It is also evident that with any fitting having a given distribution of light, the higher it is mounted the greater the area it will serve and therefore the wider the permissible spacing of fittings. On the other hand, a few fittings mounted high up will give lighting with rather harder shadows than is the case if a greater number of fittings is employed; and as the shadow effect is important, this fact must be borne in mind.

The Index of Reflector Types on page 57 indicates height spacing ratio.

This assumes that the plane of work is three feet above the floor, which is usual for machines and benches. In places such as foundries where the working plane is at floor level, some allowance must be made for this factor. It should also be remembered that it is impossible to mount fittings with the lamp actually at ceiling level. An allowance of at least one foot is necessary to provide for the reflector. It is obvious that to provide the necessary uniformity of illumination, lighting units must be arranged symmetrically, but as ceiling divisions, columns, shafting or any similar obstructions may restrict the arrangement of the fittings, it is best to draw a scale plan of the room clearly indicating all such obstructions. If no such ceiling divisions or columns exist, layouts can be planned within the limitations of the height spacing ratios given above.

Having decided upon the maximum spacing, proceed to locate the points on the diagram of the floor area, placing them as nearly symmetrical as possible without exceeding the maximum permissible spacing. The distance between the outside row of fittings and the wall should not exceed one-half of the normal spacing distance, and in places where work is carried on at benches or machines placed near the wall, this distance should be reduced to approximately one-third of the normal spacing.

The recommended spacing ratios are for units having the normal characteristics of their type, but in special cases where fittings possessing unusual characteristics are employed it will be necessary to obtain the height spacing ratio from the manufacturers. In many instances it will be found that the maximum permissible spacing is not suitable for the interior in question, and it becomes necessary to choose some closer spacing which will allow for a symmetrical layout. With a closer spacing it becomes possible to lower the fittings somewhat from the height originally selected, and while a little extra illumination will be obtained by doing so, the effectiveness of the lighting may not be increased, on account of the more oppressive atmosphere which will be produced, particularly where the fittings are already mounted fairly low.

The height and spacing of fittings arrived at by the above process is still liable to adjustment if the final result of the calculations gives an illumination level not sufficiently near the level that is aimed at.

The next step is to find the 'Room Index.' The amount of light that reaches the plane of work from a fitting is affected by its height and by the size and shape of the room, and for purposes of design calculations, rooms are classified according to their dimensions, each classification being given a letter which is known as the 'Room Index.' The Index has no mathematical meaning, but it is merely a symbol that is used for the subsequent calculation. Room Indices for many industrial interiors are shown on page 111 of the Appendices.

The room indices marked with an asterisk should be advanced two steps when only a single fitting is employed; for example, 'A*' will be altered to 'C.'

It is important to note that when direct, semi-direct, or general lighting units are being employed, the figures at the top of the various 'height' columns should be used, but where semi-direct or indirect fittings are employed the ceiling height is shown at the bottom of the columns. In each case the height is to be measured above the plane of work.

Having obtained the appropriate room index from the table, it now becomes possible to find the Coefficient of Utilization of the installation. This is the proportion of light from the lamps which is actually received on

the plane of work, and it is influenced by the reflective properties of the surroundings, by the type of fitting used, and by the Room Index.

It will be obvious that where the ceilings and walls are light in colour a large proportion of any light which reaches them will be reflected back on to the plane of work, whereas if these surfaces are dark or dirty much of the light will be absorbed and therefore lost. In the case of semi-direct and indirect lighting, the major part or the whole of the light eventually received on the plane of work reaches it by reflection from these surfaces, which must therefore be light coloured if the efficiency of the installation is to be satisfactory. A table showing reflection factors is to be found on page 76, from which it is possible to estimate reasonably closely the reflection factors of the walls and ceiling of the workshop under consideration, but a certain amount of judgment is necessary in interpreting these figures.

In a multi-storey factory, for instance, the walls and ceiling may be painted or distempered with material having a reflection factor as high as 75 per cent., but after dark, unless the windows are covered by light-coloured blinds, practically all of the light which strikes them will pass out and be lost. In such circumstances the windows should be taken as very dark surfaces, and it is therefore necessary to estimate the amount of window space in comparison with the total wall space, and thus to arrive at an estimate of the overall reflection factor of the walls. It is very unusual to find this factor to be as much as 50 per cent. even with very light-coloured distemper. A similar adjustment must of course be made in the case of the ceiling of a factory with a 'saw-tooth' roof construction.

4. Lamp size.

After the position of the units has been settled on the plan, all that remains is to calculate the size of the lamp which is required in each unit to provide the desired illumination, and it may be obtained from the following formula advised by the E.L.M.A. Lighting Service Bureau.

$$L = \frac{\text{F.C.} \times \text{A} \times \text{Dep'n Factor}}{\text{C of U}}$$

Where L = The lumens required per lamp.
F.C. = Foot-candles of illumination desired
A = Area in square feet per unit (total floor area divided by number of units).
C of U = Coefficient of utilization (find from table).
Dep'n Factor = The depreciation factor (usually assumed to be 1·43) necessary to allow for the depreciation of the installation owing to dust, dirt, etc.

Having calculated the lumens required per lamp, it is then necessary to consult the tables showing Rating and Efficiency of Incandescent Lamps on page 116 of the Appendices, to find a lamp which will give approximately this number of lumens. If the lumens required fall nearly midway between two standard lamp sizes, choose the larger rather than the smaller, or if possible, recalculate using a different height and spacing of fittings.

Here is a typical example of designing a lighting installation for an industrial interior.

Data. The floor plan of the factory space to be lighted is 72 feet by 144 feet.

The work carried on in the room is assembly of medium-sized machine parts calling for good horizontal illumination.

The supply voltage is 230.
Height from floor to roof trusses is 12 feet.
The roof is of northern light construction, dark roller blinds being used.
The walls and upper structure are painted a light colour.
Only a small amount of material is stored along the walls of the room.

Procedure. Following the steps given on the previous pages, proceed as follows:

1. Foot-candle illumination. From the table of Foot-Candle Intensities, pages 103 to 109, 12 foot-candles is recommended for assembly, medium grade, with a range of 10–15.

2. Type of light fittings. Consulting the Index of Reflector Types, page 57, the Dispersive Reflector is selected, the choice being based principally on efficiency, and ease of maintenance.

3. Location of points, mounting height and number of fittings.

The height of the benches, the working plane, is 3 feet above the floor. The maximum mounting height of the lamps above the floor area is 11 feet (12 feet to truss, less 1 foot for reflector drop). Hence, maximum mounting height of fitting above working plane is 8 feet (11 feet less 3 feet).

From the Index of Reflector Types, page 57, giving height-spacing ratio for dispersive reflectors, an 8-feet mounting height above the working plane gives a maximum spacing of 12 feet, and since the section of the room near the wall consists of gangways and storage, 6 feet may be allowed between the last row of fittings and the side walls.

Reference to the plan of the room shows that a 12-feet spacing each way (outside fittings 6 feet from walls) would give a symmetrical layout in the 24 feet by 36 feet sections, and this spacing is therefore adopted. The points for the entire spacing are marked on the plan as shown, 72 units being required.

4. Lamp size.

(*a*) Area per fitting in square feet =

$$\frac{\text{Total Floor area in sq. ft.}}{\text{Number of Points in the Room}} = \frac{72 \times 144}{72} = 144 \text{ square feet.}$$

To find the Coefficient of Utilisation:

From the Room Index, page 111, for a room 72 feet × 144 feet, where the mounting height of direct lighting fittings is 8 feet above the plane of work, the Room Index is given as E (room 80 × 140 feet, fitting height 10 feet).

Referring to the table on page 110, Coefficient of Utilisation, for Direct fittings, in a position with a Room Index of E, and where the ceiling is fairly light and the walls fairly dark in colour, the Coefficient of Utilisation is found to be 0·60. (Note that the ceiling and walls originally stated to be light in colour, are now taken to be fairly light and fairly dark respectively to allow for the dark blinds and space occupied by doors and windows.)

Taking the Depreciation Factor of 1·43, we now get:

(*b*) Lamp lumens required per fitting.

$$= \text{Foot-candles} \times \text{Area per Fitting in square feet} \times \frac{\text{Depreciation Factor}}{\text{Coefficient of Utilization}} = \frac{12 \times 144 \times 1{\cdot}43}{0{\cdot}60} = 4118.$$

From the tables on pages 116 and 117, suitable lamps are found to be 60-watt

Sodium, 125-watt Mercury, or 300-watt Tungsten. The actual illumination using these lamps will, of course, vary slightly from that originally designed for, or

$$\frac{3900 \times 12}{4118} = 11{\cdot}4 \text{ foot-candles.}$$

$$\frac{5000 \times 12}{4118} = 14{\cdot}5 \text{ foot-candles.}$$

$$\frac{3720 \times 12}{4118} = 13{\cdot}8 \text{ foot-candles.}$$

CHAPTER NINE

MAINTENANCE

WHEN illumination is to be bought, the buyer should consider his purchase on the basis of sustained 'seeing ability' per pound expended. The cost per kilowatt hour for electric power is a prime factor only when one knows how efficiently this power is converted into light.

The cost of the lamp bulb is a factor when we know the quality and quantity of radiation emitted. The value of reflectors and accessories is indeterminate until we know just how they redirect and continue to redirect the light to the work.

Even so, we must also reckon with the light that may efficiently come from the lighting unit, but which may be lost through absorption in surrounding objects or surfaces before it can reach the work under observation.

To a large degree our final criterion, 'seeing ability,' depends upon the co-ordinated efficiencies of all such factors. If the efficiency of any one of them is low or is allowed to fall off, then such a weak link weakens the chain and nullifies the good work of the neighbouring components.

Watch the losses through the neglect of the lighting installation, *i.e.* the high cost of low maintenance. Guard against the insidious losses resulting from such items as low voltage, unsuitable or old lamps, dusty reflectors, dirty walls and ceilings, empty sockets.

Where maintenance is poor and lighting systems depreciate, the losses due to neglect may be roughly classified as follows:

1. Dirty lamps and accessories.
2. Darkened or discoloured walls and ceilings.
3. Lamp bulbs of poor quality or low efficiency.
4. Empty sockets and unnoticed burn outs.
5. Old lamps past their days of usefulness.
6. Under-voltage burning of lamps.
7. Improper combination of lamp and reflector.

First consider the advantages and costs of keeping the lighting equipment clean. 'Water is cheaper than watts,' but it is appalling how seldom lamps and reflectors are properly washed. Yet washing is vital to seeing ability. A dirty window will absorb light, and, in the same way, dirty fittings will absorb it, causing losses of from 25 per cent. up to 50 per cent.

or even more. Much of this loss can be caused by dirt on the lamp itself; it is not sufficient just to clean the reflector, both must be done.

Many every-day examples exist to demonstrate the importance of removing films of dust and grease from the lighting units. For example, porcelain steel diffuser in a rather smoky machine shop when new produced a 12 foot-candles of illumination on the bench beneath. It had gradually become so dirty during weeks of neglect that less than 3 foot-candles finally resulted, meaning that the cost of light on the work had quadrupled. It meant that out of every pound spent for electricity and lamp bulbs, fifteen shillings was being wasted.

Another not uncommon example is this. Some 3·75 foot-candles were measured on the bench tops of a shirt factory. First, the reflectors were thoroughly cleaned. The foot-candles were increased to 4·68, or a gain of 25 per cent. Since the lamp bulbs were obviously old and dirty, new lamps were installed and the foot-candles moved up to 5·56, or a gain of 40 per cent. The ceiling was repainted from a dingy, smoky yellow to a lighter tint and the foot-candles grew to 6·78, or a total gain of 81 per cent. Examples of this sort could be quoted indefinitely.

The writer recently took readings of the illumination received on the working plane in a number of factories immediately before and after cleaning the reflectors. Here are a few of the results:

Industry.	Foot-candles with Soiled Reflectors.	Foot-candles with Clean Reflectors.	Percentage of Increased Illumination.
Engineering .	4	6	50
Engineering .	3	5·5	83·3
Foundry . .	6	10·5	75
Laundry . .	4	7·5	87·5
Soap Products .	5	6·5	30
Wire . .	2	3·5	75

The reflectors used were all of a modern industrial type. These facts prove beyond question that dirt can account for a loss of much more than half the light that is being paid for.

A continuous depreciation of light due to the continuing deposits of dust on reflectors and the continual ageing of lamps is to be expected. But this is not a straight line function. Usually the greatest losses occur in the first month or six weeks—about 15 per cent. in the first month is a fair average.

Dust deposited upon old dust is not so costly as the first thin layer. The loss of light from the normal and unavoidable depreciation of the lamp bulb itself from internal blackening seldom brings the final output of that lamp below 90 per cent. of its initial efficiency. However, blackening does continue as an almost straight line slope and hence a very aged lamp bulb can economically be removed and replaced by a new one should it be found to live much beyond its rated life.

How should lighting equipment be cleaned and what does it cost?

In general the experience of past years has shown that bulbs and reflectors should be wiped free of dust at least once each month. Except in

unusually dirty positions they should be washed at least once every sixty days. It is not a bad plan to alternate dry and wet cleaning.

Stubborn cases of encrusted, greasy dirt require warm water and soap or a mild grease solvent. Extreme cases of hardened sooty deposits may require a dilute solution of oxalic acid. After the usual washing with soapy water, and to avoid the soap film that will hold the next deposit of dust, wipe and dry the reflector carefully or preferably rinse in ammonia water.

Cleaning costs vary, but taken alone they average about 4 per cent. of the total operating costs of a lighting installation. If such cleaning will in itself increase the illumination 20 or 25 per cent. then the results pay for the expenditure four or five times.

The accessibility of the lighting unit (and the lamp) is very important. In industrial installations, if the bulb can be removed without taking down the globe, the maintenance is greatly simplified. In industrial installations, the 'safe-change fitting,' or disconnecting plug, facilitates removal of the reflector complete with lamp to the floor for easy washing. It is instantly detachable as a complete unit without disturbing the wires. Just what that means is shown by the following experiment.

To clean 5,700 porcelain steel lighting units, in their regular overhead position, at eight minutes each, required 45,600 minutes, or 760 hours, to clean. Labour at that time cost 1s. 3d. an hour. Therefore the cost of each complete wash was £47 10s. Considering four washes a year, the yearly cost was £190.

With a cleaning time per unit of two and a half minutes, made possible by a removable hanger, it takes 14,250 minutes, or 237½ hours, to clean 5,700 units. With labour at 1s. 3d. an hour, the cost for one complete wash is £14 16s. 10½d. The yearly cost for four complete washes is £59 7s. 6d. Thus the installation of 'safe-change fitting' effected a saving of £130 12s. 6d., or 68 per cent. of the yearly cost of keeping lights clean and efficient.

What we have discussed about dirt on the reflector applies in principle to grimy or discoloured interior surfaces. Neglecting for a moment the efficiency differences of different colours of painted surfaces, we may consider merely the losses due to the neglect of these surfaces. In an enclosed space such as a small room any change in the light reflected by the walls and ceiling will change the light available at work level almost in the same proportion.

When light falls on an opaque surface part of it is reflected and part of it is absorbed, the lighter and cleaner the surface the more light will be reflected and the more efficient will be the installation. Light-coloured walls can make a great difference to the illumination; and dirt, on the other hand, can cause serious losses.

More than half the light can be lost in some districts due to dirt, and it pays well to make sure that walls and ceilings are kept both light and clean. The table gives values of reflecting powers of various surfaces with light produced by standard gas-filled lamps.

REFLECTING FACTORS OF DIFFERENT SURFACES

Aluminium paint	.72
Black paint, matt	.6
Brick, red, clean	.25
Brick, yellow, clean	.35
Buff, light	.61
Buff, middle	.54

Caen, stone	72
Concrete, unpainted	45
Cream, deep	70
Cream. matt	62
Cream, pale	76
Deal, plain	45
Galvanised iron, unpainted	16
Glass, ordinary	14
Grey, french matt	28
Grey, dark matt	22
Green, light matt	41
Green, dark matt	27
Ivory, glossy	69
Ivory, matt	64
Plaster	75
Plaster board	60
Poplar, plain	47
Red carmine, matt	9
Salmon pink, matt	44
Steel. unpainted, structural	16
Stone, light, matt	58
Tile, white, glossy	80
White blotting paper	82
White paint, glossy	78
White paint, matt	77
White paper	84
White pine	61
Whitewash	80

Individual studies must be made to ascertain how frequently an interior may be repainted, but it seems common practice to find it economical to wash most painted interiors once a year.

How much the reflection coefficient may be increased by washing it is impossible to answer definitely, but many experiments indicate that an increase of about 10 per cent. is usual.

Our third item of neglected maintenance has to do with lamps of poor quality. The cost of the lamp bulb is small in comparison with the cost of lighting. It usually represents less than 10 per cent. of the total and a few pence difference in the cost of the bulb is really negligible, whereas a few per cent. difference in output efficiency is vitally important.

If we evaluate lighting costs properly we find that a deficiency of about 6 per cent. in the lamp efficiency is about equal to the average first cost of the lamp. Hence inefficient lamps are not economical at any cost, and if the poor lamp is 7 per cent. less efficient than a reputable good one, made to British Standard Specification, then the purchaser should really be given a bonus to compensate him for his lighting losses.

Empty sockets and unobserved dead lamps take their toll of lighting efficiency. They are just as useless as if the entire lighting units were missing. Fixed charges, such as cost of installation and investment, continue whether the socket is empty or full.

Old lamps in a properly maintained system should be removed even though still capable of burning. Fortunately lamps of reputable manufacture seldom blacken so seriously as to necessitate removal before blackout,

but there are cases on record where lamps may live much beyond the designed life and degenerate into electric heaters. They become like the hose-nozzle that might gradually be allowed to have its orifice reduced in

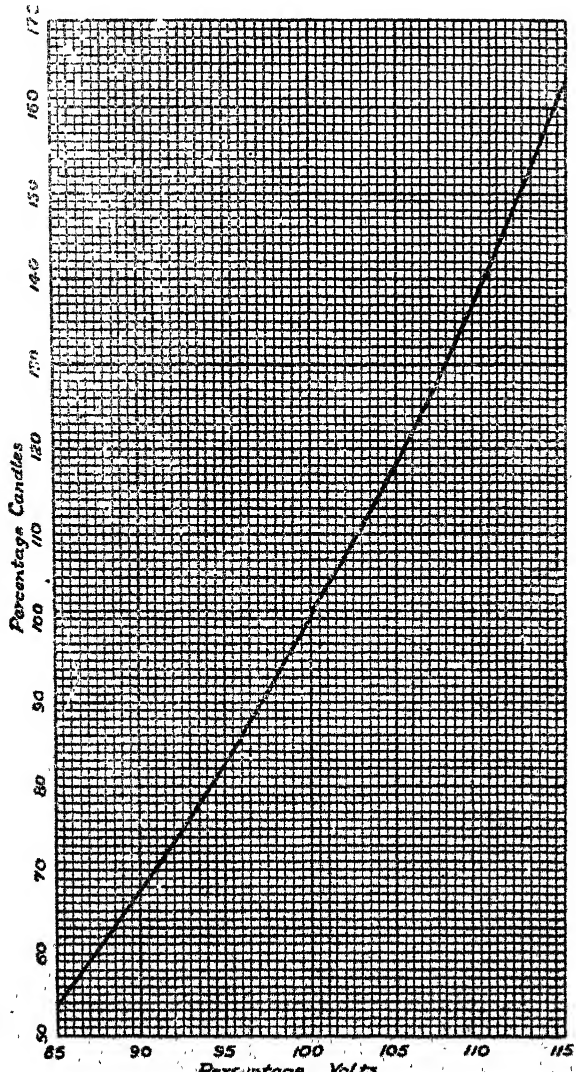


FIG. 21.—CURVE SHOWING PERCENTAGE VARIATION IN CANDLE-POWER WITH VARIATION IN VOLTAGE OF METAL FILAMENT VACUUM OR GASFILLED LAMPS

size and from which less and less water flows. Consequently the up-to-date user in many instances finds it economical to remove lamps which have burned beyond their normal period, and have become darkened.

Another vital problem in connection with the economics of maintenance is the under-voltage burning of a lamp. To a minor degree, there may be some loss in voltage due to any corroded contacts throughout the system. To a greater degree there is a voltage loss resulting from haphazardly extending or overloading branch circuits.

The voltage drop in any system should not exceed 2 per cent. This is counterbalanced, in the main, by providing a slightly excess voltage at the service entrance or the distribution panel.

The cost evaluated in units of light amounts to approximately a 4 per cent. diminution of illumination for a 1 per cent. drop in voltage. Consequently the highest economy dictates that there must be the closest possible agreement between the designed and rated voltage of the lamp and the actual socket voltage, or that the latter be not less than the former. By over-voltage burning one gains light at the cost of life.

The importance of supplying lamps of the correct voltage and the maintenance of voltage at the lamp terminals is emphasized in the accompanying diagram.

It will be observed that a reduction of 5 per cent. to the normal voltage decreases the output of the lamps by 18 per cent.

Similarly, the overrunning of the lamps produces the same percentage effect but with a corresponding diminution in the effective life of the lamps.

Finally, to secure the most seeing ability for our money we must direct our generated light to its point of usefulness. If the glass reflector be broken the light is wasted sideways, since the proper reflector usually increases the usable light from two to three times over that which comes from the bare lamp. If the metal reflector becomes tarnished or bent much the same thing occurs. If—and this is an important point—the wrong size of lamp bulb be inserted in the reflector, then the emitted beam is changed and the combination loses effectiveness.

For example, a 200-watt size R.L.M. reflector and corresponding wattage of lamp will emit light with an output efficiency of about 70 per cent. If a 150-watt lamp be inserted in this reflector the output efficiency drops to about 62 per cent. One of the best checks on this loss is to guard against the careless interchange of bulbs and accessories.

The whole secret of an efficient lighting installation after it has once been properly installed lies in planned periodic attention. Light-meter surveys are recommended in order to detect depreciation. Above all, the maintenance must be made the regular duty of a reliable employee who appreciates the value of his job.

When the illumination has decreased to 75 per cent. of its initial value the lighting equipment should be washed. Frequently a group-replacement plan of re-lamping can be established to coincide with the cleaning period with a resultant saving in maintenance costs.

To ensure that a given level of illumination will be maintained even where conditions are favourable it is necessary to design the installation to give initially 25 per cent. more light than the required minimum. In positions where dirt will collect rapidly and when adequate maintenance is not provided, the initial illumination should be at least 50 per cent. above the maximum requirement.

Good maintenance means more light—and more light for the same operating expense. No value whatever is obtained from the light lost on dirty fittings, walls or ceilings, so if this light can be reclaimed it amounts to very much the same thing as extra cash in the pocket.

The fluorescent tube which has run its life does not necessarily go out like a tungsten lamp that has failed. Moreover, if a fault develops on a tube circuit there are other components to examine besides the fuse and the flex. The following notes, taken from Osram Bulletin, will be helpful in facilitating the maintenance of fluorescent tubes and their associated equipment.

First, it is desirable to know exactly how to recognise a tube which has served its useful life.

In contrast to a tungsten filament lamp, a fluorescent tube may not cease completely to give light when it is approaching the end of its life, but may simply flicker or show other objectionable symptoms which might mislead one into suspecting not mere normal failure, but a faulty component in the circuit.

Apparent faults that may simply be symptoms of a tube which has run its full life are :

1. A tendency to flicker on and off for a long period when first switched on.
2. Material blackening of the tube at one or both sides.
3. An apparent slowing down in the cycle period, giving cycle flicker comparable with a tube on a 25-cycle installation.

Any of these symptoms may be accompanied by an excessive brightness of the cathode filament at one or both ends of the tube.

While these symptoms may be due to other causes, wherever they occur in a tube which has burnt for a period near to its rated life, the installation of a new tube is advisable.

If, however, a tube has failed prematurely or if the trouble persists after a new tube has been installed the following hints may help in the detection and remedying of faults.

A circuit which is not behaving normally should be disconnected from the supply until such time as the defect can be corrected. If a number of other circuits are operating from the same circuit switch, the tube should be removed and, if possible, the supply should be disconnected locally, otherwise damage to sound components of the circuit may be caused.

Location of faults in a circuit can often be expected by the simple procedure of trying the switch from the defective circuit in an adjacent good circuit. If the switch is in order, the same procedure should be followed with a tube taken from the defective circuit. Never try a good tube in a defective circuit until it has been established that the circuit itself is not faulty.

See that the choke is in the phase lead as this tends to minimise the effect of any troubles that occur due to an earth on any part of the circuit.

It is important to check the supply voltage with that of the equipment used and to see that the correct choke tappings are being employed.

It is worth remembering that as soon as a tube is alight, the starting switch associated with it is out of circuit and can, therefore, be temporarily removed and used for replacement or testing on an adjacent faulty circuit without affecting the operation of the tube from which it has been removed.

For schedule of symptoms, causes and remedies, see Appendices, pages 114 and 115.

CHAPTER TEN

STATUTORY REGULATIONS

THE Factories Act, 1937 (1 Edw. 8 and 1 Geo. 6, c. 67), consolidated all previous legislation affecting health, safety and welfare of workers in factories and introduced amendments of great importance for employers, works managers and welfare officers.

For the first time in English industrial history sufficient and suitable lighting was required in all factories, Section 5 of the Factories Act stating that:

(1) *Effective provision shall be made for securing and maintaining sufficient and suitable lighting, whether natural or artificial, in every part of a factory in which the persons are working or passing*

(2) *The Secretary of State may, by regulations, prescribe a standard of sufficient and suitable lighting for factories or for any class or description of factory or parts thereof, or for any process.*

(3) *Nothing in the foregoing provisions of this section or in any regulations made thereunder shall be construed as enabling directions to be prescribed or otherwise given as to whether any artificial lighting is to be produced by any particular illuminant.*

(4) *All glazed windows and skylights used for the lighting of workrooms shall, as far as practicable, be kept clean on both the inner and outer surfaces and free from obstruction:*

Provided that this subsection shall not affect the whitewashing or shading of windows for the purpose of mitigating heat or glare.

This official and belated recognition of the value of good lighting in factories empowered the Secretary of State to prescribe standards and in November, 1937, he appointed a Committee to advise as to such standards. They submitted the *Fourth Report of the Departmental Committee on Lighting in Factories*, obtainable from His Majesty's Stationery Office, Kingsway, London, W.C.2. Price 1s. 1d. post free. This Report contains the following recommendations (extracted from Form 282, March, 1939) for minimum standards for general lighting in factories:

(1) *Over the interior working areas of any factory the illumination at floor level, or at three feet below the level at which work is carried on, shall not fall below 1·0 foot-candle, without prejudice to the illumination required for the work itself.*

'Working area' may be taken to mean the area occupied by, and in the immediate vicinity of, the machines, benches, or other plant at which the operatives stand or sit in the execution of their work, including the intervening gangways, alleys, and similar spaces.

(2) *Over all interior parts of any factory, other than the working areas, over which persons employed are liable to pass, the illumination at floor level shall not fall below 0.5 foot-candle.*

(3) *Over all open yards, passages, roadways, and other open places in a factory, upon which persons are employed or over which they are liable to pass, the illumination at ground level, or at other level of employment or passage, shall*

not fall below 0·1 foot-candle, without prejudice to the illumination required for the work itself, or for the adequate lighting of dangerous parts and places o other emergency.

The Chief Inspector of Factories shall have power to approve a lower standard in appropriate cases.

(4) *Where any light source in a factory is less than sixteen feet in height above floor level, no part of the source or fitting having a brightness greater than* 10 *candles per square inch shall be visible to any person whilst normally employed within one hundred feet of the source, unless the angle of elevation from the eye to the source exceeds* 20 *degrees.*

(5) *All local light sources in a factory shall be provided with suitable shades of opaque material or other effective means by which they shall be completely screened from the eyes of every person employed at a normal working place.*

(*A* local light *is intended to mean a light so placed as to illuminate only the area or part of the area of work of a single operative or small group of operatives working near to each other*)

(6) *Adequate means shall be provided as far as reasonably practicable, by suitable screening or placing or other effective method, to prevent discomfort or injury by the reflection of light from smooth or polished surfaces into the eyes of the worker.*

(7) *Adequate means shall be taken as far as reasonably practicable to prevent the formation of shadows which interfere with the safety of or cause discomfort to any person employed.*

(8) *No light source which flickers or undergoes abrupt changes in candle power in such manner as to interfere with the safety or efficiency of any person employed shall be used for illumination of a factory.*

The outbreak of war held up this development and the Departmental Committee was asked to submit a fresh report in the light of war conditions. Their findings were given in the *Fifth Report of the Departmental Committee on Lighting in Factories* published by His Majesty's Stationery Office, price 4d. post free.

The following are extracts from this report :

Generally speaking, two features characterize industrial work in a large number of factories at the present time. In the first place, the work has to be done at high pressure and much greater strain is imposed on the worker. Secondly, owing to the prevalence of night work and overtime, the time spent under artificial light is far longer, even in factories which provide adequate natural light. In pre-war days, for example, a working day of 8 *a.m. to* 5.30 *p.m. connoted the use of artificial light for about* 10–15 *per cent. of the yearly hours of employment ; at present it is often* 50 *to* 100 *per cent.*

We have been unable to find any evidence that prolonged or even continuous work under artificial light has any deleterious effects upon health or safety, though it may be that at a later stage such effects may be established. It is obvious, however, that the present conditions of work in many factories (especially in factories completely obscured) are unnatural and new to the majority of workers. We are accordingly agreed that exposure to such conditions justifies the maintenance of a higher standard of lighting than that previously recommended by us, in the interests both of the workers and of increased production.

RECOMMENDATIONS

In respect of interior work places.

In our previous report we recommended a minimum illumination of 1 foot-candle at floor level for the 'working areas' of factories. We feel that this minimum can no longer be regarded as generally adequate and that it is desirable to lay down a standard based on what is usually accepted as good illumination, enabling ordinary work to be done with ease and affording reasonable amenity to the workers affected. In factories generally we think that a minimum of 6 foot-candles at three feet above floor level should be attained, relaxation from this standard being allowed to certain large shops (such as are found in steel works, heavy engineering works, boiler-making works, etc.) in which the maintenance throughout of such a high standard would as a rule hardly be practicable owing to the presence of overhead cranes, and other obstructions which necessitate the light sources being mounted at considerable heights from the floor.

We therefore recommend that:

(1) Over the interior parts in which persons are regularly employed the illumination shall be not less than 6 foot-candles without prejudice to any additional illumination required by the nature of the work.

Provided that in parts of factories where persons are employed, in which the mounting height of the light sources necessarily exceeds twenty-five feet measured from the floor, or where the structure of the room prevents the uniform provision of this standard, the illumination shall not be less than 2 foot-candles, and not less than 6 foot-candles where actual work is being done, without prejudice to any additional illumination required by the nature of the work.

The illumination shall be measured in the horizontal plane at a level of three feet from the floor.

In respect of interior passage and access.

We see no reason to alter the standard previously suggested by us and accordingly recommend that:

(2) Over all interior parts over which persons employed are liable to pass other than those in which persons are regularly employed, the illumination shall not be less than 0·5 foot-candles.

In respect of other parts of factories.

There are, of course, several parts of factories not falling within any of the foregoing categories, such as store-rooms, stockrooms, engine houses, etc. These, however, are relatively unimportant from the point of view of lighting and we think it unnecessary to make any specific recommendations.

In respect of processes requiring discrimination of detail.

In our previous report we stated that while we were unable to formulate definite standards for work of varying degrees of fineness, we suggested that the Committee might usefully continue its work by investigating on a fundamental basis the relation between the fineness of the work and the illumination required. Though circumstances unfortunately have prevented the adoption of this plan, we would direct attention to a code of recommended values for processes in different categories which has been published by the Illuminating Engineering Society and generally accepted as being in accordance with the best practice.

Reflection factor of surroundings.

The mere quantity of light provided is by no means the only factor in good lighting, and present conditions have emphasized the importance of relieving the effects of the black-out by maintaining the surroundings (including the

ceilings, walls, floors, benches and interiors of blacked-out windows and roof-lights and, where possible, the plant) light in colour.

The visits to factories paid by us as well as evidence tendered to us, have convinced us that the depressing and gloomy appearance of many factories could be greatly relieved and even neutralized by more careful attention to this matter.

We accordingly recommend that:

(3) *Throughout the interior parts, in which persons are regularly employed, walls, partitions, ceilings, tops of rooms, including interior surfaces of windows and rooflights through which the passage of daylight is continuously prevented, and as far as practicable, other structural fixtures, which are less than twenty feet above floor level, shall be maintained light in colour*

Suppression of glare.

Glare is still prevalent in many factories, especially those in which antiquated systems of lighting are in use. We therefore see no reason to modify our previous recommendations which ran as follows:

(4) *Where any light source in a factory is less than sixteen feet height above floor level, no part of the source or fitting having a brightness greater than ten candles per square inch shall be visible to any person whilst normally employed within one hundred feet of the source, unless the angle of elevation from the eye to the source exceeds 20 degrees.*

(5) *All local light sources in a factory shall be provided with suitable shades of opaque material or other effective means by which they shall be completely screened from the eyes of every person employed at a normal working place.*

(6) *Adequate means shall be provided as far as reasonably practicable by suitable screening or placing or other effective method to prevent discomfort or injury by the reflection of light from smooth or polished surfaces into the eyes of the worker.*

Whilst confining our recommendations in (4) to sources mounted at heights below sixteen feet which should serve to eliminate serious cases of glare, it is desired to emphasize that some care is necessary in the case of sources mounted at a higher level. Even in these circumstances the use of brilliant unscreened sources is preferably avoided.

The conclusion reached by us is that it is of little use to tinker with an out-of-date installation, and that the best and easiest course is to make a good job of it and replace it by modern equipment. We understand that the Electricity and Gas Supply industries are prepared to advise on this matter.

Avoidance of shadows:

It appears that there are still cases in which troublesome shadows occur, and we suggest therefore that our former recommendation should be retained. It runs as follows:

(7) *Adequate means shall be taken, as far as reasonably practicable, to prevent formation of shadows which interfere with the safety of, or cause discomfort to, any person employed.*

Substantially the recommendations of the Fourth and Fifth Reports are the same except in one very important item, the recommended minimum illumination for working areas, which was increased from 1 foot-candle at floor level in the Fourth Report to 6-foot-candles at three feet above floor level in the Fifth Report.

This very startling increase in a period of less than two years was undoubtedly due to war factors. First, the very much longer hours of

working under artificial light had enabled the Committee to be entirely satisfied that ills which had in the past been attributed to bad lighting were not only undoubtedly due to this cause, but that their effect was very rapidly cumulative and increased progressively as working hours under artificial light increased.

Second, quantity and quality of production for the first time became a National as distinct from a private interest, and in framing recommendations for proposed legislation the Committee were able to consider, positively, evidence as regards improvement in factory output and quality, which previously they had been entitled to consider only negatively as an offset to the cost of any improvements introduced from the welfare point of view.

The Government, in the person of the Ministry of Labour and National Service, who have taken over responsibility for this particular aspect of industry, which was previously handled by the Home Office, accepted almost *in toto* the recommendations of the Fifth Report and drafted legislation making the adoption of these recommendations compulsory in all factories working more than 48 hours a week.

Section 5 of the Factories Act, 1937, permits the Minister, by regulations, to prescribe a 'sufficient and suitable' standard of illumination for all factories. This was done as:

STATUTORY RULES AND ORDERS, 1941, No. 94

FACTORIES

THE FACTORIES (STANDARDS OF LIGHTING) REGULATIONS, 1941, DATED JANUARY 14, 1941, MADE BY THE MINISTER OF LABOUR AND NATIONAL SERVICE UNDER SECTION 5 OF THE FACTORIES ACT, 1937 (1 EDW. 8 & 1 GEO. 6. C. 67) PRESCRIBING A STANDARD OF LIGHTING FOR CERTAIN FACTORIES.

In pursuance of section 5 (2) of the Factories Act, 1937, and of all other powers enabling him in that behalf, the Minister of Labour and National Service hereby makes the following Regulations.

1. Subject as in these Regulations provided, these Regulations shas apply to factories in which persons are being regularly employed in a proces or processes for more than 48 working hours a week, or in shifts, provided that nothing in these Regulations shall be deemed to require the provision of lighting of a specified standard in any building or structure so constructed that it would not be reaonably practicable to comply both with such requirement and with any defence requirement as to the non-display or obscuration of lights.

2.—(*a*) The general illumination over those interior parts of the factory where persons are regularly employed shall be not less than 6 foot-candles measured in the horizontal plane at a level of three feet above the floor:

Provided that in any such parts in which the mounting height of the light sources for general illumination necessarily exceeds 25 feet measured from the floor or where the structure of the room or the position or construction of the fixed machinery or plant prevents the uniform attainment of this standard, the general illumination at the said level shall

be not less than 2 foot-candles, and where work is actually being done the illumination shall be not less than 6 foot-candles or the greatest reasonably practicable illumination below 6 foot-candles.

(b) The illumination over all other interior parts of the factory over which persons employed pass shall when and where a person is passing be not less than 0·5 foot-candles measured at floor level.

(c) The standards specified in this regulation shall be without prejudice to the provision of any additional illumination required to render the lighting ufficient and suitable for the nature of the work.

3.—(a) Where any source of artificial light in the factory is less than sixteen feet above floor level, no part of the source or of the lighting fitting having a brightness greater than 10 candles per square inch shall be visible to persons whilst normally employed within 100 feet of the source, except where the angle of elevation from the eye to the source or part of the fitting as the case may be exceeds 20°.

(b) Any local light, that is to say an artificial light designed to illuminate particularly the area or part of the area of work of a single operative or small group of operatives working near each other, shall be provided with a suitable shade of opaque material to prevent glare or with other effective means by which the light source is completely screened from the eyes of every person employed at a normal working place, or shall be so placed that no such person is exposed to glare therefrom.

(c) So far as reasonably practicable, arrangements shall be made, by suitable screening or placing or other effective method, to prevent discomfort or injury by the reflection of light from smooth or polished surfaces into the eyes of the worker.

4. Adequate measures shall be taken, so far as reasonably practicable, to prevent the formation of shadows which cause eye-strain or risk of accident to any person employed.

5.—(a) Where the Chief Inspector of Factories is satisfied in respect of any particular factory or part thereof or in respect of any description of workroom or process that any requirement of these regulations is inappropriate or is not reasonably practicable, he may by certificate in writing (which he may at his discretion revoke) exempt the factory or part thereof or description of workroom or process from such requirement to such extent and subject to such conditions as he may specify in the certificate.

(b) Regulation 2 (a) shall not apply to the factories or parts of factories respectively specified in Part I of the Schedule to this Order, and nothing in Regulation 2 shall apply to the parts of factories specified in Part II of the said Schedule.

6. These Regulations may be cited as the Factories (Standards of Lighting) Regulations, 1941, and shall come into force on the first day of February, 1941.

Signed by Order of the Minister of Labour and National Service this fourteenth day of January, 1941.

T. W. Phillips,
Secretary of the Ministry of Labour and National Service.

SCHEDULE

PART I.

Cement works.
Lime, whiting and plaster works.
Works for the washing and grinding of limestone.
Gas works.
Coke oven works.
Electrical stations.
Flour mills.
Provender and compound food mills
Maltings and breweries.

Parts of factories in which the following are carried on:
Concrete or artificial stone making.
The making of tar-macadam or other road materials.
The conversion of iron into steel.
The smelting of iron ore.
Iron or steel rolling.
Hot rolling or forging, tempering or annealing of metals.
Glass blowing and other working in molten glass.
Tar distilling.
Petroleum refining and blending.
Extraction of petrol from shale oil.

PART II.

Parts of factories in which light sensitive photographic materials are made or used in an exposed condition.

Copies of tee Regulations can be obtained from His Majesty's Stationery Office or through any bookseller, price 1d.

CERTIFICATE OF EXEMPTION: CHEMICAL WORKS

In pursuance of the power conferred on me by the above Regulations, I hereby exempt from the requirements of Regulation 2 (*a*) of the Regulations, workrooms in chemical works in which processes in the manufacture of chemicals are carried on, subject to the following conditions:

The general illumination over those parts of such workrooms where work is being carried on shall be not less than 2 foot-candles, and the illumination at the normal working places in those parts shall be not less than 6 foot-candles, measured in each case in the horizontal plane at a level of three feet above the floor.

A. W. GARRETT,
H.M. Chief Inspector of Factories.

FACTORY DEPARTMENT,
MINISTRY OF LABOUR AND NATIONAL SERVICE.
19th February, 1941.

CERTIFICATE OF EXEMPTION: DANGER BUILDINGS OF EXPLOSIVES WORKS

In pursuance of the power conferred on me by the above Regulations, I hereby exempt from the requirements of Regulations 2 (*a*), 3 (*a*) and 3 (*b*)

of the Regulations, danger buildings of explosives works which are at present lit by bulkhead lights or external lights, or in which, on account of the risk of fire or explosion due to the presence of explosives, the nature or position of the lighting fittings is specified for the building in a licence granted by the Secretary of State under the Explosives Act, 1875.

A. W. GARRETT,
H.M. Chief Inspector of Factories

FACTORY DEPARTMENT
MINISTRY OF LABOUR AND NATIONAL SERVICE.
2nd April, 1941

Copies of the Regulations can be obtained from His Majesty's Stationery Office or through any bookseller, price 1d

In a letter dated 15th October, 1940, sent to all employers, likely to be affected by the new lighting regulations, attention was drawn to the following points :

Scope of the Regulations

It is only proposed at present to apply the Regulations to those factories in which persons are being regularly employed in a process or processes for more than forty-eight working hours a week or in shifts. This does not mean that poor lighting is unimportant in other factories, but in present circumstances lighting improvements may raise the question of priority of supplies ; and where the lighting is not already up to the standards of sufficiency and suitability specified its improvement is particularly important in the case of those factories in which long hours or shifts are being regularly worked—these being, broadly speaking, the factories in which work of special national importance is being done at high pressure and work is carried on to an exceptional extent by artificial light. The Chief Inspector would have power to grant exemptions from particular requirements of the Regulations in special cases where they are inappropriate or not reasonably practicable.

Sufficiency of illumination

Regulation 2 requires, for interior lighting, at least 6 foot-candles in parts in which persons are regularly employed, and half a foot-candle in other parts ; but this does not mean that higher illumination need not be provided for special classes of work. The 6 foot-candle standard is based on what is now usually accepted as good illumination, enabling ordinary work to be done with ease and affording reasonable amenity to the workers affected. Provision is made for a lower standard than 6 foot-candles in certain cases where structural difficulties are involved (see the proviso to Regulation 2 (a)) ; some classes of works or parts of works are exempted from Regulation 2 (a) or from the whole Regulation (see Schedule to the Regulations) ; and for other exceptional cases there is the Chief Inspector's power of exemption.

Many employers do not know whether their lighting provides an illumination of a specified number of foot-candles, and this cannot be accurately ascertained without a light-measuring instrument. To help employers to find out whether their present lighting requires improvement in order to attain the standards prescribed in Regulation 2, the Tables printed as an Appendix to this letter[1]

[1] Reproduced in the Appendices to this book.

were published by the Factory Lighting Committee ; they show whether illuminations of 6, 2 and ½ foot-candle at bench or floor level are likely to be given with typical electric lamps at various heights. It should be noted that :

(i) *The tables have been prepared primarily to assist in checking existing lighting installations ; it is recommended that new installations or improvements should only be carried out in conjunction with expert advice.*

(ii) *The tables are based on the use of efficient modern types of reflectors and lamps ;* if the reflectors are shallow and unsuitable or dirty or the lamps are old or dirty, much lower illumination will result.

Reflection from light-coloured surroundings.

The mere quantity of light provided from the light-source is by no means the only factor in good lighting and present conditions have emphasized the importance of relieving the effects of the black-out by light-coloured surroundings, walls, ceilings, insides of roof shutters, etc., which add to the general brightness of a room, afford an effective background to dark objects and at the same time increase the illumination derived from a light-source of a given strength. The Factory Lighting Committee attached great importance to this.

Standards of suitability.

Glare and the formation of objectionable shadows are common features of unsuitable lighting. There are many factories in which the illumination is sufficient in amount, but in which lights are so badly placed or shaded that the workers are exposed to conditions of glare which dazzle or strain the eyes, impair working efficiency, and increase the accident risk. Marked shadows at points near the work or across gangways, etc., may also impair efficiency and lead to accidents. Regulations 3 and 4 are designed to secure that the lighting is up to a certain standard in these matters.

Most modern types of electric lamps and incandescent gas mantles are brighter than 10 candles per square inch, and Regulation 3 has the effect of requiring that they shall be equipped with reflectors of suitable depth or diffusing bowls. Such fittings, if of modern design, may also ensure proper concentration over the working plane of all available light. Thus in many cases, in which antiquated fittings are st ll in use, it will be found that the substitution of reflectors of modern type w ill result in illuminations of the intensity required by Regulation 2 without any i ncrease in the power of wattage of lamps.

The following questions, which serve as a useful basis for any factory executive when reviewing the lighting conditions of a particular works, have been taken from *Engineering Bulletin*, published by the Ministry of Labour and National Service.

Adequacy.

1. Is the lighting adequate for carrying on the work ? Do the workers sit or stand naturally, or is there a tendency to peer into the work ? Is there much spoilt work ?

2. Are all the dangerous parts of the machinery or plant adequately lighted ?

3. Is the lighting adequate to afford safe access from one part of the factory to another ?

4. Are the walls and ceilings kept light in colour ? Are the windows cleaned periodically and kept unobstructed on the inside ? Are the artificial light sources in good condition and kept clean ?

Suitability.

1. Is the whole area made use of by the workers sufficiently lighted ? Do the light sources flicker ?

2. Does any near source of light shine directly into the worker's eyes ? If the sources are shaded, are the shades deep enough ? Should the sources be raised ? If highly polished material is used, is adequate provision made for the prevention of reflection ?

3. Shadows. Are the light sources placed to prevent the shadow of any worker or any part of the plant falling on the material worked on ? Would the provision of additional sources tend to eliminate shadow ?

To sum up, here is the B.T.H. Factory Lighting Code, which throughout industry should be the ideal at which to aim :

1. The lighting of the factory should be regarded from the point of view of the inhabitant, and not from that of the casual observer.
2. The illumination provided must be adequate and suitable.
3. Glare, whether direct or reflected, should as far as possible be eliminated.
4. Shadows, which interfere with the safety of, or cause discomfort to, any person employed, should be avoided.
5. Remember the value of the psychological factor, and make the surroundings of the workshop as bright and comfortable as possible.
6. Maintain all installations in a state of cleanliness and efficiency.

CHAPTER ELEVEN

PRODUCTION, ASSEMBLY AND INSPECTION PROCESSES

ALL of the problems discussed in this chapter are found in a wide variety of industries and the methods by which they are solved are applicable to most industrial lighting problems. The investigator determined the visual requirements of every process concerned and then decided upon the most satisfactory illumination from the standpoint of quality, quantity, direction, contrast and brightness. Investigation was then continued to discover the best methods of providing this illumination. The resulting solutions are the best possible ones, though not the only ones, under given conditions.

Each problem investigated involved visual tasks more than usually severe, and in each instance an effort was first made to discover whether several lights from fixed sources spaced more or less uniformly throughout the area would be satisfactory. Experiments were made with levels of illumination up to 90 foot-candles, provided by standard equipment and utilizing both incandescent and gaseous illuminations singly and in combination. In no instance was this found entirely satisfactory. This must not be construed that general lighting of an industrial area is unnecessary or that local lighting alone is sufficient.

Research into the complex process of seeing, shows the necessity for lighting the entire surroundings of the object as well as the object itself,

and further indicates the desirability of a value of illumination of surroundings approaching that of the object. While in many cases it is not at present practicable to meet this condition fully, general lighting, where local lighting is necessary, should be materially better in quantity and quality than has previously been the case.

From the standpoint of age, health, work, comfort, psychology and conservation of energy, there is no question as to the value of a complete lighting application. It is well known how gloomy and harsh is local lighting surrounded by darkness, as contrasted with the cheerfulness and stimulation of a well-lit interior. Therefore the values of general lighting as laid down by The Factory Department are taken for granted. Safeguards such as freedom from glare and reasonable uniformity are also implied.

As an example of an industry utilizing many industrial production processes, a factory specializing in radio sets is excellent from all points of view.

Beginning in the production laboratory where new designs and models are built and tested, technicians are accommodated at benches along the walls or back to back with a high fence between. On these benches the new models are built piece by piece until the complete chassis is ready for testing. This process naturally requires considerable manipulation of the chassis as it is taking form, and the handling of small parts and connections. The light meter read 50 foot-candles for the average job, with requirements up to 200 foot-candles for finer details. General illumination of 15 foot-candles is recommended here, with local lighting provided by two deep concentrating reflectors with 60-watt lamps on flexible arms for each worker. This will provide the maximum illumination required. Flexibility of control of the light is highly important in order that the engineers may follow the position of the work, and maximum shielding of the light source to avoid glare must be secured.

The tool design department of our radio factory is the department where sharp detail drawings are made on regulation draughtsmen's boards. This is often done in places where the ceiling is of usual factory type, not permitting standard indirect lighting. Local lighting, or general lighting from small sources, does not provide the necessary diffusion for illuminating the objectionable shadows around T-squares and triangles, and often gives rise to harmful reflections from shiny paper and instruments.

A large, indirectly lighted canopy approximately four feet square (about the size of the usual draughtsman's table), suspended over each table and about eight feet above the floor, with a unit of 500 watts, provides diffused illumination of 40 foot-candles.

Tool-making is usually done in a shop containing layout benches, sensitive drills, presses, shapers, milling machines, grinders and lathes. Probably the most difficult operation is that of scribing at the layout benches. It has been the custom, because of inadequate artificial light, to place these benches beneath the workshop windows. The daylight thus used is generally supplemented by local lighting, but the men usually cease work when daylight is insufficient.

This causes great loss of output at considerable expense, because these men are most skilled and highly paid. Proper artificial lighting is therefore of great value.

Extreme accuracy is absolutely essential in scribing. The operation consists of a toolmaker placing a block of tool steel upon his layout bench,

coating the steel surface with copper sulphate solution which leaves a thin copper deposit, and then inscribing the outlines of the tool or die by means of sharp steel instruments.

The scribing involves all types of plane geometric designs such as irregular curves, tangents to curves, etc. The scribing instruments bite through the copper film into the steel, so that the resulting visual job is that of seeing the scribed lines against the copper background. This copper background is of two finishes; one is bright or specular, and the other is machined or partially diffusing. Therefore there are two ways in which light must be applied.

In the case of the shiny surface, if the light is directed to the surface in such a way that the reflection is towards the eye, the copper background becomes so bright that the eye cannot distinguish the scribed lines. But if the light is directed obliquely to the surface from the side, and the block is so orientated that the majority of the scribed lines are normal to the direction of the incident light, the lines will stand out in bright relief against a dark background.

The reason is that the light which strikes the sloping edge of the groove, which has been gouged by the scribing instruments, is reflected to the eye, while the light striking the smooth surface of the block is reflected away from the eye. The direction of the light should be 45 degrees or more from the vertical and its source should be of such size that the entire block is illuminated lengthwise as well as crosswise. At least 50 foot-candles of illumination is necessary.

In the case of a machined or matt surface there is another possible method. Since the surface is slightly diffusing, the light can be directed on the block from the front towards the worker, but at an oblique angle. The result is a bright copper-coloured background with the scribed lines standing out darkly against it.

The scribed line is a continuous gouged-out cavity with rough pockets, so that the light is either trapped or reflected away from the eye. By contrast with the surface of the block the line is dark.

The incident light must be directed at an angle of 45 degrees or more from the vertical in order to direct any specular reflection away from the eye. A horizontal illumination of about 100 foot-candles is necessary for good visibility.

The ideal light source would be a continuous parabolic reflector of a length equal to the blocks worked on, with well-shielded lamps. But since it must be mounted close to the work to meet the directional requirements, its size imposes a limitation that at present limits its use.

Two alternatives provide a satisfactory solution. First is the use of deep concentrating reflectors with a well-shielded 60-watt lamp, mounted on adjustable arms. For small dies up to nine inches a single reflector is sufficient.

On larger dies, two reflectors side by side, on a single arm, are satisfactory. The reflectors must be so constructed as to be cool enough to avoid annoyance when touched with head or arm because they are in the work area. The second alternative is the use of a very deep double half-shade, integral with the socket cover mounted on an adjustable arm.

Notice should be taken of the disadvantages of supplementary lighting under control of the worker, but the conditions are so varied, and workers so definitely craftsmen, that rigidity of lighting is really impracticable within the limits of engineering sense.

Similar reasoning applies to lighting of the work on the machines where the dies and tools are made, for the same block with its scribed lines is simply transferred from bench to machine. Local lighting is, of course, necessary. Due to machine limitations the size of the lighting equipment is limited while flexibility is of the greatest importance. Not less than 20 foot-candles of general illumination is desirable throughout the tool room.

The press room. Here the dies finished in the tool-making department are placed in the presses and stampings made.

A difficult press operation is where all the holes are stamped in a radio chassis on one operation and some of the holes extruded for threading in the same operation. Three plates are used in this process. The upper plate, containing all the punches, is attached rigidly to the movable jaw of the press. The middle plate is a stripper through which the punches pass on their way down to punch the metal sheet and which strips the metal tabs from the regular punches when the jaws open. The lower plate is the die plate. The blank metal sheet of appropriate size is placed over the die plate.

The breaking of punches is a frequent trouble. This is caused by the small punched-out metal pieces adhering to the extruding punches as they are drawn out of the die, and which are not stripped off because the tabs are smaller than the holes in the stripper plate. Due to lack of light, the operator fails to notice them clinging to the punches, and in the next operation they cause the punch to snap off. Also, very frequently these small metal pieces fall off on the flat surface of the die, and when the operator does not see them a lump is raised in the chassis during the next operation. When a punch is broken it means a great waste of time for repairs, and also £1 to £2 for a new punch. Thus it is most important to have the press properly illuminated so that when it is open after each operation the worker can see at a glance any of these small metal pieces and remove them.

The usual way of lighting the presses is to hang a bare 60-watt lamp with wire guard behind the jaws of the press just high enough so that when the jaws are open the operator cannot see the lamp. The light falls upon the oily film on the die plate of the stripper plate, if there is one, and is reflected specularly to the eye. If any foreign material lodges on either of these plates in the line of the path of light it can be detected only by silhouette. Since the light source is small, there is only a very narrow path of light across the plate and anything not in this path is apt to be missed. The undersides of the punches are supposed to be illuminated by light reflected from the oily film on the plates, but generally this light is so feeble as to leave the punches in darkness.

From inspection of this problem it appears that standard lighting is a step in the right direction, but needs to be amplified to make it ideal. Because of the construction of the press, the light must be thrown in obliquely. Very little is seen by direct illumination. It is more by silhouette that the little metal pieces can be detected. They lie between the reflection of the light source in the oil film, and show up dark against a light background. If the plate is of any size there must be a large light source to give a reflected image of uniform appearance and brightness over the entire plate. A diffusing trough reflector, having opal glass across its opening and tilted at an angle to give the maximum projected area towards the plates, is an ideal solution. The size of the translucent area directed towards the plates can be determined by taking the position of the eyes of the workers and drawing in the limiting reflected rays that will include the whole plate. The position

of the trough behind the jaws of the press is determined by the mechanical construction.

When illuminating presses from the rear, vision is almost entirely by silhouette. Under these conditions, less light is required than when vision depends on direct discrimination of detail. Similarly, elimination of direct and reflected glare is highly important, otherwise vision will be obscured. Under these conditions illumination of the order of 2 foot-candles is enough.

In actual practice, two mechanical features are often found which seriously interfere with the execution of lighting from the rear. On small presses, with small parts, compressed air is often used to speed up the operations by blowing the part out of the die into a container or chute at the rear of the press. With this chute it is impossible to use a trough and the suggested arrangement is to use a deep half-shade on an adjustable arm and swing the reflector around to one side of the front, preferably to the left, throwing the light in from the front.

In such conditions vision depends upon reflected light, and since the objects to be seen are dark coloured, more incidental illumination is required than in the case of rear lighting. About 10 foot-candles illumination is found necessary.

The second mechanical hindrance is the practice of using two operators per machine, one at the front and one at the rear. This is often the practice on large presses where two or three operations are carried on. The feed operator places the blank and watches the first operation, then the second operator takes the part from the first operator and places it in the second set of guides and watches this operation. Sometimes as many as four operations are carried on between them. The position of the second operator precludes any possibility of mounting a full-length trough reflector at the rear of the press. Due to the possibility of these multiple operations on all large presses, a compromise is to use deep half-shades on adjustable arms at each corner of the presses, adjust the lighting units to be free of the operations and of the operators, and direct the light into the jaws of the press. This is an unfortunate departure from the normal as the light sources are not of a diffused nature, but are concentrated in small reflectors and produce streaks across the oily surface instead of uniform reflection.

A satisfactory solution for all lighting unit positions is to use rectangular reflectors about eight inches to twelve inches long and three inches to six inches wide, or round reflectors of equivalent mouth area, with a diffusing medium of opal glass or plastic translucent material over the mouth of the reflector. These would be mounted on adjustable arms so that the reflectors could easily be adjusted to throw the maximum light into the press and yet clear the movements of the operators. If glass is used in the reflectors a guard should be provided.

General lighting of press rooms approximating 10 foot-candles is desirable from the standpoint of safety, cleanliness and comfort.

The machine shop in our radio factory consists of machines for manufacturing small machine parts, such as screwing machines, lathes, special milling machines, etc. In order to see the fine detail of the work adequately, as well as the mechanism of the machines themselves, it is necessary to have a good level of general illumination (20 foot-candles or more) to relieve the harsh contrasts in the working area, and in addition to use well-designed local lighting to light the vital areas to values of 50 to 100 foot-candles. Since the operations are so diversified, and the part that is worked on is held in different planes, it is essential to have flexibility of adjustment of the

local lighting units. This can be accomplished best by use of a deep shad on an adjustable arm.

Sheet-metal fabrication involves work on layout benches where scribing is done, and work on the forming benches, shears, welders, drills, etc. Sheet-metal scribing is a very exacting task because of the accuracy which must be maintained in scribing the lines, and because the lines are very hard to see due to the lack of contrast between the line and the surface. In addition, the surface reflects everything within the field of view, the ceiling pipes, walls and even the face of the sheet metal worker.

With these confusing images it is difficult to make the scribed lines stand out in bold relief, or contrast well with the rest of the polished surface. This can be accomplished by erecting a light canopy over the sheet-metal table, its size approximating to the size of the sheet worked upon, and arranged so that a uniform reflection is obtained in the sheet. The brightness of the canopy should be low, not exceeding 500 foot-lamberts, so that the reflection is comfortable.

When a line is scribed, by means of a sharp instrument, on the polished surface, it causes an interruption in the reflection of the canopy; thus the lines stand out in strong contrast, either lighter or darker than the background, depending upon the operators' position. Under these conditions it is easy accurately to scribe any geometrical design.

On the forming benches it is necessary closely to watch the scribed lines and eliminate confusing images. Accordingly the same principle holds good and the same type of equipment is satisfactory. Over the guillotine a length of trough equal to the length of the shear is essential; and over the shear, a long narrow trough, centred over the narrow space between the guard and the shear blade, produces a narrow band of light on the sheet to be cut out. The scribed line can then readily be seen and accuracy observed in shearing on the line.

An illumination of approximately 40 foot-candles is required and can be obtained from a trough using 150-watt lamps on eighteen-inch centres when the trough is placed seven to eight feet above the floor. A general illumination of 15 foot-candles is recommended here.

Wax engraving consists of stamping and building. A copper plate is covered with a thin layer of white wax. A plate of type, containing the required data, is stamped down under pressure into the wax. This leaves a slight shadow impression.

It is then necessary to build up the background with wax, resulting in deep impressions for the letters and figures. This is done so that when the plate is immersed in the plating bath the copper electro-type produced will have sharp, well-defined figures. The type is very fine and consequently the running in of molten wax around these small impressions is most exacting and delicate. A strip of wax is held in the left hand against the building tool, which has a head similar in shape to a small soldering iron with a fine point, and is held in the right hand. Because the building tool is heated the wax melts, flows down to the fine tip, and is distributed by moving this tip around the impressions as the wax runs off.

Because the detail consists of shadow impressions, the greater the shadow the stronger the contrast and the greater the resulting visibility. However, the surface of the wax is glossy enough to reflect objectionable highlights unless the light source is large and diffused. General indirect lighting from the ceiling was tried out as well as diffused lighting from an overhanging hood. But both resulted in a deadening of the detail because the necessary

shadow effect in the impressions was decidedly reduced. Consequently the problem resolved itself into so controlling the light that it is swept across the plate at about 45 degrees from a large diffused low-brightness source. In order to clear the movements of the engraver the light could only come from the front. It was found that the diffused quality of the light coming from the sky through the lower sash of a window was ideal, the engravers wishing to ultilize this so long as it was adequate in quantity. But they wished to supplement it with the same quality when the illumination fell off on a cloudy day or in late afternoon. So the arrangement shown in the sketch was developed. An illumination of 40 foot-candles is required on the plate with a general illumination of 10 foot-candles.

The assembly processes in radio factories are carried on at long benches with ten to fifteen girls at a bench. At the back of the bench are vertical sections containing shelves where parts are stored within handy reach of each girl. These vertical sections are divided into compartments approximately three feet six inches long, and each compartment is numbered. There is a girl every three feet six inches working on some part of the assembly of a chassis, and when the end of the line is reached the chassis is complete, ready for inspection.

The lighting problem in such circumstances consists of meeting the following conditions:

1. Vertical lighting of the terminals and parts to which connections are to be made.

2. Lighting from the side to eliminate the shadow of the workers' heads.

3. Lighting units mounted high enough to be out of the way of both the worker and the foreman as he occasionally bends over to see the set upon which she is working. Also from the viewpoint of radiant heat, the fitting should be mounted above and away from the worker.

4. A wide enough beam to give good overlap so that when the light is cut out from one side by the arm or tool there will be enough from the other side to see easily.

5. Equal components of light from each side. Otherwise the shadow from the stronger fitting will be so dense as to make it difficult to see details with the weaker light from the other side. This necessitates the use of a lighting unit on each side of the worker.

6. Proper illumination with minimum of wattage to keep the radiant heat at a minimum. The heat is a very important consideration and very radically affects the morale of the worker.

Study of the problem showed that an illumination of 50 foot-candles was needed for soldering wiring connections to terminals, the most exacting visual task of the operation. The work is very close, and the girls are working against time. Speed and good workmanship are the two essentials.

One trial consisted of the use of a diffusing canopy over the bench. This was found to flatten detail and required almost double the illumination scheduled for good visibility. Another trial was the use of standard R.L.M. reflectors, but these were not only too diffused but lacked the directional flux. A third method was tried, the use of concentrating reflectors directed from each side of the area in front of each girl. This produced hard shadows and insufficient overlapping.

The successful method was achieved by the use of an asymmetric two-way directional unit with maximum beam at 45 degrees but having a sufficiently wide beam to give complete overlapping. Thus was obtained

semi-diffusion, which eliminates distracting shadows but still gives hight lights to prevent wire and terminals from being flattened into the background. With a 150-watt lamp the proper amount of illumination was obtained. The units were spaced three feet six inches apart and thirty inches above the working plane. Throughout the room 10 foot-candles of illumination was necessary.

When the radio chassis have been released for inspection they are carried by a trolley conveyor to the cabinet assembly room where they are installed in the cabinets. The cabinets are placed on a roller conveyor in an upright position. Then the chassis are put in from the back and screwed into place and the dials are put on the front.

The lighting problem is a matter of general lighting with a heavy vertical component and close enough spacing to have a good overlap so that light will come into the set from more than one side. Standard lighting equipment having maximum candle-power at approximately 45 degrees and adequately shielded to eliminate glare is satisfactory. Vertical illumination of 10 foot-candles is adequate, and will be obtained when a general lighting of about 20 foot-candles is provided from each equipment.

When a radio chassis leaves the assembly line it goes to the preliminary inspection table. Here the inspectors use button-hooks and pull on every connection to see if there are any loose joints which will give way under stress. Then they check the circuiting with batteries and ammeter. This is very close work and requires speed and entails severe eye work, since the eyes are darting here and there very rapidly and continuously, taking in every detail. The metal parts are of matt cadmium plating with fine solder points and then upright terminals. Also the inspectors must bend over the set to see the connections on the far side of the set.

The problem here is to light the parts from every direction and at the same time avoid the shadows of the inspector's head. Well-diffused lighting of about 75 foot-candles is desirable for this work.

Several trials were made and two considered satisfactory. The first method was by means of a large diffusing canopy four feet square and mounted seven feet above the floor, using 300-watt shielded bowl lamps, which eliminated the possibility of shadow from the inspector's head or hands, in the set.

The other method was to use four large industrial reflectors with 200-watt shielded bowl lamps so arranged in a cluster above the bench so as to simulate a fairly uniform diffusing surface of large area, similar, in fact, to the canopy described above. While this does not give the degree of diffusion of the canopy it is a satisfactory solution and a practical economic compromise. General lighting of about 10 foot-candles is desirable if the tables are in a large area. In a small confined area the reflected light from the tables produces comfortable seeing conditions.

The inspection of the cabinet for flaws and scratches is particularly important. Imperfections in the smoothness of the surface must be detected. In order to see these imperfections and to eliminate specular reflection from the polished surfaces and dial it is necessary to direct the light on to the surfaces obliquely. There should be sufficient lateral spread to throw light from the sides as a man stands in front of the cabinet. The intensity should not be too great because the average home where the radios will be used seldom have more than 20 foot-candles around the radio set. Besides it is impossible to eliminate all flaws in woodwork. It was found that 40 foot-candles vertical illumination was sufficient.

To comply with these conditions a parabolic reflector was used with a 300-watt lamp and a spread lens to give side spread, mounted twelve feet high and spaced five feet apart. It is necessary to mount these reflectors high and tilt them down quite obliquely 30 degrees from vertical to prevent glare in the eyes of the workers who are putting the finishing touches on the chassis in the cabinets. For the work behind the cabinet inspection line, a good general lighting is approximately 20 foot-candles. This illumination also serves to balance the higher level of oblique illumination directed to the front of the cabinets and hence produces a more comfortable working condition.

APPENDICES

		PAGE
I.	Units and Terms	100-102
II.	Foot-Candle Intensities	103–109
III.	Tables and Data—	
	Coefficient of Utilisation	110
	Room Index	111
	Fuse Wires	112
	Approximate Current Rating of Fuse-Links	113
	Maintenance of Fluorescent Tubes	114–115
	Rating and Efficiency of Incandescent Lamps	116
	Rating, Performance and Dimensions of Electric Discharge Lamps	117
	Hours of Lighting in a Year	118
	Tables showing Approximate Lamp Sizes at Various Heights and Spacings	119–120
	Conversion Tables	121–122

I

UNITS AND TERMS

BRIGHTNESS : The brightness of a surface should not be confused with the illumination received by it. Any object emitting or reflecting light is said to be bright, and through the fact of its brightness, is visible. The degree of brilliancy of any part of the surface or medium when viewed from a designated direction may be measured. Glare may be caused by extremely high brightness or by excessive contrast of brightness between two surfaces.

Brightness is the quotient of the luminous intensity of a surface measured in a given direction by the area of this surface projected on a plane perpendicular to the direction considered. (In practice no surface exactly obeys the cosine law of emission or reflection—hence the brightness of a surface is usually not uniform, but varies with the angle at which it is viewed.)

Various units of brightness are used, the two units appearing in this book being as follows:

A brightness of 1 *candle per square inch* indicates that each square inch of projected surface is emitting 1 candle-power in the direction being considered.

A brightness of 1 *equivalent foot-candle* is the average brightness of any projected surface emitting or reflecting 1 lumen per square foot, i.e., if a piece of white paper, which has a reflection factor of 80 per cent., is illuminated to 10 foot-candles, the brightness of the paper will be $10 \times \frac{80}{100} = 8$ equivalent foot-candles.

The relationship between equivalent foot-candles (or foot-lamberts) and candles per square inch is such that 1 candle per square inch = 452·4 equivalent foot-candles, and 1 equivalent foot-candle = 0·00221 candles per square inch.

CANDLE-POWER : The candle-power of a source is a measure of intensity of light given out in a stated direction. It cannot be taken as a direct measurement of the quantity of light emitted from that source, but knowledge of the candle-power of a source in various directions may be necessary in order to ascertain the illumination received from that source.

If the source is mounted h feet above the working plane, d being the distance in feet from the source to the point on that plane at which the illumination is to be measured, and θ being the angle between the direction of the ray of light and the vertical to the plane at that point, then the illumination received at that point will be $I = \frac{C.P. \times \cos\theta}{d^2}$ foot-candles,

or $I = \frac{C.P. \times \cos^3\theta}{h^2}$ foot-candles.

COEFFICIENT OF UTILIZATION : The proportion of the lumens prod[illegible] by the lamps which reaches the plane of work. It is dependent upo[illegible] type of diffusing and reflecting equipment, colour of walls and ceiling, also the proportions of the room, that is, the size and shape of the [illegible]

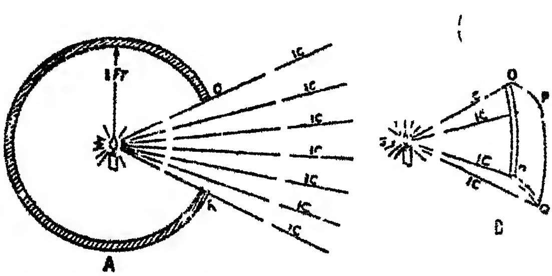
and the height of the light source above the plane of work. The plane work is usually considered to be horizontal and two and a half feet abo the floor.

DEPRECIATION FACTOR: This is a factor which allows extra initi illumination to compensate for the falling off in reflecting efficiency of th reflectors, walls and ceilings, due to deterioration and the collection of dus and dirt. A depreciation factor should always be applied to the recom mendations for foot-candles of illumination, since these are always state in terms of average service or sustained illumination.

FOOT-CANDLE: A foot-candle is the unit of illumination and is a measure of degree to which a surface is illuminated. If 1 lumen is distributed evenly over 1 square foot of surface the illumination is said to be 1 foot-candle. Similarly, 5 lumens per square foot = 5 foot-candles, and so on. A source of 1 candle-power will illuminate to a value of 1 foot-candle a surface, every point of which is at a distance of 1 foot.

LIGHT: Light is energy radiating in straight lines from a source, natural or artificial, at a speed of approximately 186,000 miles a second. Light itself is invisible, but light rays reflected from an object into the retina of the eye create an illuminated image of that object which is transmitted to the brain and interpreted into the sensation of seeing and a conception of the object observed. For the purposes of illuminating engineering, light is radiant energy evaluated in proportion to the luminous sensation produced by it.

LUMEN: A lumen is the unit of light flux, representing a quantity of light. One lumen is the total amount of visible light intercepted by or falling upon a surface of 1 square foot, every part of which is at a distance of 1 foot from a uniform point source of 1 candle-power. From this it follows



(A) Opening O R has area of 1 sq. ft. and emits one Lumen.
(B) One Lumen falls on surface O P Q R.

FIG. 22.—DIAGRAMMATIC REPRESENTATION OF ONE LUMEN

that a uniform point source of 1 candle-power emits 4π (or 12·57) lumens, is to convert mean spherical candle-power to lumens, multiply by 12·57. Lamps are rated for efficiency in the units lumens per watt. The maximum theoretical efficiency of an incandescent lamp emitting just visible radiation is 621 lumens per watt.

LUX: A lux is the Continental unit of illumination, and is such that 1 lux = 0·093 foot-candle, or 1 foot-candle = 10·76 lux.

Diffusion and Reflection:

Diffusing surfaces and media are those which break up the incident light and distribute it more or less in accordance with the cosine law, as, for example, rough plaster and opal glass.

Redirecting surfaces and media are those which change the direction of the light in a definite manner, as in a mirror or a prism.

Scattering surfaces and media are those which redirect the light into a multiplicity of separate pencils by reflection or transmission, e.g. rippled glass.

Regular or specular reflection is that in which the angle of reflection is equal to the angle of incidence.

Diffuse reflection is that in which the light is reflected in all directions.

Perfectly diffuse reflection is that in which the reflected light is distributed in accordance with the cosine law so that the reflecting surface appears equally bright from all angles of view. The reflection from a body may be regular, diffuse, or mixed. In most practical cases there is a superposition of regular and diffuse reflection.

The regular reflection factor of a surface or a body is the ratio of the regularly reflected light to the incident light.

The diffuse reflection factor of a surface or a body is the ratio of the diffusely reflected light to the incident light.

The reflection factor of a body is the ratio of the light reflected by the body to the incident light. It is the sum of the regular and the diffuse reflection factors.

Diffuse transmission is that in which the transmitted light is emitted in all directions from the transmitting body.

Regular transmission is that in which the transmitted light is not diffused. In such transmission the direction of a transmitted pencil of light has a definite geometrical relation to the corresponding incident pencil. When the direction of the light is not changed the transmission is called direct.

Perfectly diffuse transmission is that in which the transmitted light is distributed in accordance with the cosine law so that the surface of the transmitting body appears equally bright from all angles of view. (The transmission of light by a body may be regular, diffuse or mixed. In many practical cases there is a superposition of regular and diffuse transmission. It should be noted also that transmission factors as defined below refer to the ratio of light emerging from the body concerned to the light incident upon it. Reflections at the surfaces as well as absorption within the body, therefore, operate to reduce the transmission.)

Since the transmission and reflection factors depend in general on the angle of incidence, this angle should be stated. If the angle is not given, incidence is assumed to be practically normal. Transmission and reflection factors frequently vary also with the quality of light used and consequently it should be specified or the illuminant should be stated.

The regular transmission factor of a body is the ratio of the diffusely transmitted light to the incident light.

The transmission factor of a body is the ratio of light transmitted by the body to the incident light. It is the sum of the regular and the diffuse transmission factors.

The absorption factor of a body is the ratio of the light absorbed by the body to the incident light. (The absorbed light is the difference between the incident light and the sum of the transmitted and reflected light.)

II

RECOMMENDED FOOT-CANDLE INTENSITIES FOR INDUSTRIAL INTERIORS

	Average foot-candles recommended.	Range.
ASSEMBLING SHOP:		
Rough Work	8	6–10
Medium Work	12	10–15
Fine Work	20	15–25
Extra fine work	35	25–50
BAKERY	8	6–10
BOOKBINDING:		
Folding, assembling, pasting, cutting, punching and stitching, embossing .	12	10–15
CANNING	12	10–15
CHEMICAL WORKS:		
Hand furnaces, boiling tanks, stationary driers, stationary or gravity crystallizing, mechanical furnaces, generators and stills, mechanical driers, evaporators, filtration, mechanical crystallizing, bleaching	5	4–6
Tanks for cooking, extractors, percolators, nitrators, electrolytic cells . . .	8	6–10
CLAY PRODUCTS AND CEMENT:		
Grinding, filter pressing, kiln rooms .	8	6–10
Moulding, pressing, cleaning and trimming	12	10–15
Enamelling	12	10–15
Colouring and glazing	12	10–15
CLOTH PRODUCTS:		
Cutting, inspecting, sewing, pressing, cloth treating (oil cloth, etc.)		
Light goods	12	10–15
Dark goods	20	15–25
COAL BREAKING AND WASHING, SCREENING:		
Control points	3	2–4
Picking belts	20	15–25
DAIRY PRODUCTS	8	6–10
DIE SINKING	35	25–50

	Average foot-candles recommended.	Range.
ELECTRICAL MANUFACTURING:		
Battery manufacture, coil and armature winding, mica working, insulating processes	12	10–15
ENGRAVING	Over 50	
FLOUR MILLING:		
Cleaning, grinding, or rolling . .	8	6–10
Baking or roasting	8	6–10
Flour grading	20	15–25
FOUNDRY:		
Charging floor, tumbling, cleaning, pouring, shaking out	8	6–10
Rough moulding and core making . .	8	6–10
Fine moulding and core making . .	12	10–15
GLASS WORKS:		
Mix and furnace rooms, pressing, glass-blowing machines, polishing . .	5	4–6
Grinding, cutting glass to size, silvering .	8	6–10
Fine grinding, bevelling, inspection, etching and decorating	20	15–25
Glass-cutting (cut glass), inspecting fine .	35	25–50
GLOVE MANUFACTURING:		
Cutting, pressing, knitting, sorting, stitching, trimming and inspecting . .	20	15–25
HAT MANUFACTURING:		
Dyeing, stiffening, braiding, cleaning, refining, forming, sizing, pouncing, flanging, finishing, ironing . . .	12	10–15
Sewing	20	15–25
ICE MAKING	5	4–6
INSPECTING:		
Rough	8	6–10
Medium	12	10–15
Fine	20	15–25
Extra fine	35	25–50
JEWELLERY AND WATCH MANUFACTURING	35	25–50

	Average foot-candles recommended.	Range.
LAUNDRY AND DRY CLEANING :		
Receiving and checking	12	10–15
Washing	5	4–6
Drying room	5	4–6
Calendering	12	10–15
Ironing and pressing	12	10–15
Sorting and checking	12	10–15
Despatch	8	6–10
LEATHER MANUFACTURING :		
Vats	3	2–4
Cleaning, tanning and stretching	5	4–6
Cutting, fleshing and stuffing	8	6–10
Finishing and scarfing	12	10–15
LEATHER WORKING :		
Pressing and winding :		
Light or dark	12	10–15
Grading, matching, cutting, scarfing, sewing :		
Light	20	15–25
Dark	35	25–50
MACHINE SHOPS AND FITTING SHOPS:		
Rough bench and machine work	8	6–10
Medium bench and machine work, ordinary automatic machines, rough grinding, medium buffing and polishing	12	10–15
Fine bench and machine work, fine automatic machines, medium grinding, fine buffing and polishing	20	15–25
Extra fine bench and machine work, grinding (fine work)	35	25–50
OFFICE BUILDINGS :		
Book-keeping and typing rooms	12	10–15
Cashiers' counters	12	10–15
Corridors and stairways	3	2–4
Drawing offices	35	25–50
Enquiry offices, filing rooms, reception rooms	8	6–10
General offices	10	8–12
Other offices	12	10–15
PACKING :		
Crating	5	4–6
Boxing	8	6–10

	Average foot-candles recommended.
PAINT MANUFACTURING . . .	12
PAINT SHOP:	
Dipping, spraying, firing . . .	8
Rubbing, ordinary hand painting and finishing	12
Fine hand painting and finishing . .	20
Extra fine hand painting and finishing (automobile bodies, piano cases, etc.) .	35
PAPER BOX MANUFACTURING .	8
Storage of stock	5
PAPER MANUFACTURING:	
Beaters, grinding	8
Calendering	12
Finishing, cutting and trimming . .	20
PLATING	8
POLISHING AND BURNISHING . .	12
POWER HOUSE:	
Boilers, coal and ash handling, storage battery rooms	5
Auxiliary equipment, oil switches and transformers, switch boards, engines, generators, blowers, compressors . .	8
PRINTING INDUSTRY:	
Matrixing and casting, miscellaneous machines, presses	12
Proof reading, lithographing, electrotyping	20
Linotype, monotype, type-setting, imposing, stone engraving	35
Sorting and packing	8
RUBBER MANUFACTURING AND PRODUCTS:	
Calenders, compounding mills, fabric preparation, stock cutting, tubing machines, solid tyre operations, mechanical goods building, vulcanizing . .	8
Bead building, pneumatic tyre building and finishing, inner tube operation, mechanical goods trimming, treading .	8

	Average foot-candles recommended.	Range.
SHEET METAL WORKS:		
Miscellaneous machines, ordinary bench work, punches, presses, shears, stamps, welders, spinning, fine bench work .	12	10–15
Tin plate inspection	20	15–25
SHOE MANUFACTURING:		
Hand turning, miscellaneous bench and machine work	12	10–15
Cutting, lasting and welting (light) . .	12	10–15
Stitching	35	25–50
Inspecting and sorting	20	15–25
MITH SHOP:		
Rough forging	5	4–6
Fine forging and welding . . .	8	6–10
SOAP MANUFACTURING:		
Kettle houses, cutting, soap chip and powder	5	4–6
Stamping, wrapping and packing, filling and packing soap powder . . .	8	6–10
TEEL AND IRON MILLS, BAR, PLATE AND WIRE PRODUCTS:		
Soaking pits and reheating furnaces	3	2–4
Charging and casting floors . . .	8	6–10
Muck and heavy rolling, shearing rough by gauge, pickling and cleaning . .	5	4–6
Plate inspection	12	10–15
Automatic machines, rod, light and cold rolling, wire drawing, shearing, fine by line	12	10–15
ONE CRUSHING AND SCREENING:		
Belt conveyor tubes, main line shafting spaces, spacing, chute rooms, inside of bins	3	2–4
Primary breaker room, auxiliary breakers under bins	3	2–4
Screen rooms	5	4–6
ORE:		
Heavy	3	2–4
Light	5	4–6
RUCTURAL STEEL WORKS . .	8	6–10

	Average foot-candles recommended.	Range.
SUGAR GRADING.	20	15–25
SWEET MAKING	12	10–15
TESTING:		
Rough	8	6–10
Fine	12	10–15
Extra fine instruments, scales, etc. . .	35	25–50
TEXTILE MILLS:		
Cotton		
Spinning—		
Opening, scutching, lapping and carding	5	4–6
Drafting and twisting	8	6–10
Ring spinning	8	6–10
Warping—light goods	8	6–10
„ dark goods	12	10–15
Drawing frames	20	15–25
Weaving—		
Looms	12	10–15
Burling and mending	35	25–50
Perching	Over 50	
Cloth rooms, warehouses, etc. . .	5	4–6
Silk		
Winding, throwing, dyeing	12	10–15
Quilling, warping, weaving and finishing—light goods	8	6–
„ dark goods	12	10–
Woollen		
Spinning—		
Scouring, washing, etc.	5	4–
Grading and sorting	12	10–
Combing, carding, twisting . . .	8	6–
Warping—light goods	8	6–
„ dark goods	2	10–
Weaving—		
Looms	12	10–
Burling and mending	35	25–
Perching	Over 50	
Cloth rooms, warehouses, etc. . .	5	4–
TOBACCO PRODUCTS:		
Drying, general	3	2–
Grading and sorting	20	15–
Stripping	8	6

	Average foot-candles recommended.	Range.
UPHOLSTERING:		
Automobile, coach and furniture . .	12	10–15
WAREHOUSE	3	2–4
WELDING	12	10–15
WOOD WORKING:		
Rough sawing and bench work . .	8	6–10
Sizing, planing, rough sanding, medium machine and bench work, glueing, veneering, cooperage	12	10–15
Fine bench and machine working, fine sanding and finishing . . .	20	15–25

Illumination of 30 or more foot-candles may in some instances be pro-[illegible] from a general lighting system. In other cases it will be found more [illegible]omical to provide a combination of general lighting plus supplementary.

COEFFICIENT OF UTILISATION

Find room index from page 111.

Estimate reflection factor from table on pages 76 and 77.

Lighting Fittings.	Ceiling.	Fairly Light (40%).		Very Light (70%).	
	Walls.	Fairly Dark (25%).	Light (50%).	Fairly Dark (25%).	Light (50%).
	Room Index.	Coefficients of Utilisation.			
Direct (A) Open Reflectors such as Standard Dispersive and Reflectors for Tungsten/Mercury and Sodium.	A	·39	·43	·39	·44
	B	·43	·46	·43	·47
	C	·50	·53	·50	·54
	D	·55	·58	·56	·59
	E	·60	·64	·61	·65
	F	·65	·68	·66	·70
Direct (B) Reflectors with enclosed globe such as Industrial Diffusing Fitting (Tungsten, Tungsten/Mercury and Blended Tungsten and Mercury).	A	·24	·27	·25	·29
	B	·27	·30	·28	·32
	C	·31	·33	·32	[illegible]
	D	·35	·36	·36	·40
	E	·39	·40	·40	[illegible]
	F	·42	·44	·45	[illegible]
Semi-Direct Enclosed fittings with major light flux downward.	A	·25	·29	·26	[illegible]
	B	·28	·32	·29	[illegible]
	C	·34	·38	·36	[illegible]
	D	·37	·42	·41	[illegible]
	E	·43	·47	·46	[illegible]
	F	·48	·51	·51	[illegible]
General Enclosed Diffusing fittings.	A	·20	·24	·23	[illegible]
	B	·23	·27	·26	[illegible]
	C	·29	·32	·33	[illegible]
	D	·32	·36	·37	[illegible]
	E	·38	·42	·44	[illegible]
	F	·43	·46	·50	[illegible]
Semi-Indirect Pendant fittings with major light flux upward.	A	·11	·15	·16	[illegible]
	B	·13	·17	·18	[illegible]
	C	·17	·22	·24	[illegible]
	D	·20	·25	·28	[illegible]
	E	·24	·28	·34	[illegible]
	F	·29	·32	·40	[illegible]
Indirect Indirect Pendant fittings.	A	·08	·10	·15	[illegible]
	B	·10	·12	·18	[illegible]
	C	·13	·15	·23	[illegible]
	D	·16	·18	·26	[illegible]
	E	·19	·21	·32	[illegible]
	F	·22	·24	·38	[illegible]

ROOM INDEX

Room width	Room length	DIRECT, SEMI-DIRECT AND GENERAL FITTINGS — Height of fitting above plane of work—FEET						
FEET	FEET	5	10	14	18	22	26	30
8	10	A*						
	12	A*						
	16	B						
	24	B						
	35	B						
	50	C	A					
10	10	B*						
	14	B*						
	20	B						
	30	C						
	40	C	A					
	70	C	B	A				
12	12	B*						
	18	B*						
	24	C	A					
	35	C	A					
	50	D	B					
	90	D	B	A				
[illegible]	16	C*	A*					
	30	D	B					
	50	D	B	A				
	80	D	C	B				
	120	D	C	B	A			
[illegible]	20	D	B	A				
	40	D	B	A				
	60	D	C	B	A			
	100	D	C	B	B			
	140	D	C	B	B	A		
[illegible]	30	E	C	B	A			
	60	E	D	B	B	A		
	100	E	D	C	B	A		
	140	E	D	D	B	B	A	A
[illegible]	40	E	D	C	B	A		
	80	E	D	D	B	B		
	140	E	D	D	C	B	B	B
[illegible]	60	F	E	D	C	B	B	B
	100	F	E	D	D	C	B	B
	200	F	E	E	D	D	C	C
[illegible]	80	F	E	E	D	C	C	B
	140	F	E	E	D	D	D	C
[illegible]	100	F	F	E	D	D	C	C
	200	F	F	E	E	D	D	D
[illegible]	120	F	F	E	E	D	D	D
	200	F	F	F	E	E	D	D
		7½	15	21	27	33	39	45
		Ceiling height above plane of work—FEET						
		SEMI-INDIRECT AND INDIRECT LIGHTING FITTINGS						

FUSE WIRES

Current in amperes at which wire will fuse

S.W.G.	Diameter. Inches.	Current in Amperes. Copper.	Alloy. (Tin 1; Lead 2)	Tin.
46	·002	1·25	0·155	0·183
44	·003	1·85	0·237	0·296
42	·004	2·59	0·333	0·415
40	·005	3·41	0·440	0·55
38	·006	4·76	0·610	0·76
36	·007	6·79	0·870	1·09
34	·009	9·04	1·16	1·44
32	·010	11·50	1·48	1·84
30	·012	14·15	1·82	2·27
29	·013	15·50	2·02	2·52
28	·014	18·44	2·37	2·96
27	·016	21·50	2·76	3·45
26	·018	24·75	3·18	3·96
25	·020	29·00	3·73	4·65
24	·022	33·43	4·30	5·36
23	·024	38·10	4·90	6·11
22	·028	48·0	6·17	7·69
21	·032	58·6	7·54	9·40
20	·036	70·0	9·00	11·22
19	·040	81·5	10·45	13·07
18	·048	107·7	13·86	17·27
17	·056	132·5	17·05	21·52
16	·064	165·8	21·34	26·58
15	·072	198·0	25·46	31·75
14	·080	232·0	29·82	37·15
13	·092	286·0	37·8	46·0
12	·104	344·0	44·3	55·0
11	·116	405·0	52·2	65·0

APPROXIMATE CURRENT RATING OF FUSE-LINKS COMPOSED OF TINNED WIRE OR STANDARD ALLOY* WIRE IN BRITISH STANDARD CUT-OUTS

Current rating.	Tinned Copper Wire.		Standard Alloy* Wire.	
	Diameter (in.).	S.W.G.	Diameter (in.).	S.W.G.
1.	2.	3.	4.	5.
amps.				
1·8			0·0164	27
3·0	0·006	38	0·024	23
5·0	0·0084	35	0·032	21
8·5	0·0124	30		
10·0	0·0136	29		
15·0	0·020	25		
17	0·022	24		
20	0·024	23		
24	0·028	22		
30	0·032	21		
37	0·040	19		
46	0·048	18		
53	0·048	18		
60	0·056	17		
64	0·056	17		
83	0·072	15		
100	0·080	14		

Note—The current ratings given in this table refer to the normal maxi-n current of the circuit and do not refer to the overload at which the out will operate.

The values of the currents given in above table are approximately those ssary to comply with British Standard Specification No. 88. Where outs are known to conform to this Specification the size stated by the nfacturer on the case of the cut-out should be adhered to in preference at given above, if the cut-out is loaded to its fullest capacity.

*The term 'Standard alloy' refers to the tin-lead alloy (63 per cent. tin, er cent. lead) specified in B.S.S. No. 88.

MAINTENANCE OF FLUORESCENT TUBES

1. *From the Behaviour of the Tube*

Symptom.	Possible Cause.	Remedy.
The tube flickers on and off.	1. Tube has run full life. 2. Faulty or starting switch tending to switch on and off. Examination of the switch in such cases usually discloses that an excess glow persists when the tube is operating, or 3. Faulty tube. *Note.*—Low line voltage, low ambient temperature, or cold draughts may be contributing factors.	1. Replace tube. 2. Replace starting switch. 3. Replace tube.
Tube has the appearance of the whole light column moving, usually in the form of a spiral.	This usually occurs only when the tube is new, and disappears after a short period of use.	Switching the t off and re-starting a a few seconds is o a cure. If the ef continues for a l period replace the tu
Apparent slowing down of the cycle flicker to 25-cycle periods.	Tube has probably run its full life.	Replace tube.
The tube does not light up when switched on but both filaments are alight.	Switch contacts have locked in the closed position.	Replace switch. temporary remedy m be to give the switc tap, which may ca contacts to open.
Tube does not light, and one filament only is glowing.	Earth fault on switch or radio suppressor circuit. May be a short inside the radio suppressor or an earth on the wiring.	If earth is not det able on the wiring, place radio suppre unit.

Symptom.	Possible Cause.	Remedy.
When the tube is switched on nothing lights up at all.	1. Broken tube filament.	1. Can be detected by careful examination and if discovered tube must be replaced.
	2. Starting or switch failing to close,	2. Replace switch. If new switch also fails to close, examine the circuit with a test lamp for a break at any part.
	or 3. Break in some part of the circuit.	3. Examine circuit with test lamp and repair any break.

2. *From the Performance of the Starting Switch*

Symptom.	Possible Cause.	Remedy.
Switch con- cts lock in the osed position.	May be due to the shorting of the resistance in the radio suppressor unit.	Replace the suppressor.
Glow persists hile lamp is urning.	Low extinction voltage.	Replace starting switch. If glow persists with new switch, fault is probably in the tube, which should be replaced.
Switch elec- odes loose in lb.	This may be caused by an earth in the switch lead.	Check wiring and put in new switch.
Too rapid peration of arting switch. his will result the lamp itching on and f as the fila- ents have no ne to heat up.	Faulty switch.	Replace switch.

ondenser and resistance supplied as a single unit are termed the radio ressor.

RATING AND EFFICIENCY OF INCANDESCENT LAMPS

Dimensions and Ratings of Standard Incandescent Lamps *Pearl and Clear Lamps*

Watts	Type	Bulb Dimensions: Length, mm.	Bulb Dimensions: Diameter, mm.	Light Centre Length, mm.	Standard Cap.	Nominal Lumens: 100–130v.	Nominal Lumens: 200–250v.
15	Pearl	92·5±3·5	55±1	65±3	B.C.	140	124
25	Pearl	100·0±3·5	60±1	70±3	B.C.	240	225
40	Pearl	110·0±3·5	60±1	80±3	B.C.	470	415†
60	Pearl	117·5±3·5	65±1	85±3	B.C.	790	700†
75	Pearl	125·0±3·5	70±1	90±3	B.C.	1,060	930†
100	Pearl	137·5±3·5	75±1	100±3	B.C.	1,500	1,340†
150	Pearl	160·0±4·5	80±1	120±4	B.C.	*	2,090
200	Clear	178·0±5·5	90±1	133±5	E.S.	*	2,900
300	Clear	233·0±7	110±1·5	178±6	G.E.S.	*	4,720
500	Clear	267·0±8	130±1·5	202±7	G.E.S.	*	8,470
750	Clear	300·0±9	150±1·5	225±8	G.E.S.	*	13,610
1,000	Clear	300·0±9	150±1·5	225±8	G.E.S.	*	19,100
1,500	Clear	335·0±9	170±1·5	250±8	G.E.S.	*	30,300

* Lumens for these Lamps approx. 11 per cent, higher than corresponding high voltage Lamps.
† Coiled-coil Lamps.

Dimensions and Ratings of Electric Discharge Lamps

Watts	Type	Bulb Shape	Overall length (m/m)	Diameter (m/m.)	Cap	Specified Average Life (hours)	Nom[inal] initi[al] Lig[ht] outp[ut] (lume[ns])
80	Mercury	Pear	160±4·5	80±1	3 pin B.C.	1,500	3,04
125	Mercury	Pear	178±5·5	90±1	3 pin B.C.	1,500	5,00
250	Mercury	Tubular	290±10	48±3	G.E.S.	1,500	9,00
400	Mercury	Tubular	325±15	48±3	G.E.S.	1,500	18,00
80	Fluorescent Mercury	Pear	178±5·5	110±1·5	3 pin B.C.	1,500	3.04
125	Fluorescent Mercury	Pear	233±7	130±1·5	G.E.S.	1,500	5,00
400	Fluorescent Mercury	Isothermal	330±15	165±3	G.E.S.	1,500	15,2
400	Fluorescent Mercury	Tubular	325±15	115±2	G.E.S.	1,500	14,8
300	Mercury-Tungsten	Tubular	285±15	85±1	G.E.S.	1,500	6,3
500	Mercury-Tungsten	Tubular	380±20	100±1	G.E.S.	1,500	12,5
80	Mercury with 'black' bulb	Pear	160±4·5	80±1	3 pin B.C.	1,500	
125	Mercury with 'black' bulb	Pear	178±5·5	90±1	3 pin B.C.	1,500	
45	Sodium	Tubular	250±20	50±2	B.C.	2,500	2,50
60	Sodium	Tubular	310±20	50±2	B.C.	2,500	3,90
85	Sodium	Tubular	425±20	50±2	B.C.	2,500	6,10
140	Sodium	Tubular	540±25	65±2	B.C.	2,500	10,6

RATING, PERFORMANCE, AND DIMENSIONS OF ELECTRIC DISCHARGE LAMPS

Type	Bulb shape	Rating Watts	Nominal initial efficiency (Lumens per Watt)	Nominal initial light output (Lumens)	Life* (Hours)	Overall length (mm.)	Diameter (mm.)	Cap.
Mercury	Pear	80	38	3,040	1,500	160	80	3 pin B.C.
Mercury	Pear	125	40	5,000	1,500	178	90	3 pin B.C.
Mercury	Tubular	250	36	9,000	1,500	290	48	G.E.S.
Mercury	Tubular	400	45	18,000	1,500	325	48	G.E.S.
Fluorescent Mercury	Pear	80	38	3,040	1,500	178	110	3 pin B.C.
Fluorescent Mercury	Pear	125	40	5,000	1,500	233	130	G.E.S.
Fluorescent Mercury	Isothermal	400	38	15,200	1,500	330	165	G.E.S.
Fluorescent Mercury	Tubular	400	37	14,800	1,500	325	115	G.E.S.
Mercury-Tungsten	Tubular	300	21	6,300	1,500	285	85	G.E.S.
Mercury-Tungsten	Tubular	500	25	12,500	1,500	380	100	G.E.S.
Sodium	Tubular	45	55·5	2,500	2,500	250	50	B.C.
Sodium	Tubular	60	65	3,900	2,500	310	50	B.C.
Sodium	Tubular	85	71·5	6,100	2,500	425	50	B.C.
Sodium	Tubular	140	71·5	10,000	2,500	540	65	B.C.

* In practice it will be found that discharge-lamps will continue burning for longer than the period shown, but in order to secure the most economical service they should be replaced in order to avoid the drop in efficiency which occurs subsequently.

HOURS OF LIGHTING IN A YEAR, EXCLUDING SUNDAYS

Daily Lighting.	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total per annum.
From one hour before Sunset to:													
6 p.m.	79	53	31							48	71	94	376
7 p.m.	107	77	58	18					20	74	100	120	574
8 p.m.	133	100	84	41	5			17	46	101	126	141	794
9 p.m.	160	124	111	64	31	17	21	43	72	128	152	166	1089
10 p.m.	187	148	137	88	56	43	48	67	98	154	178	192	1396
11 p.m.	214	172	164	112	82	69	75	94	124	181	203	217	1707
Midnight	240	196	190	135	108	94	101	120	149	207	229	244	2013
2 a.m.	293	244	243	183	158	146	154	170	200	260	280	295	2646
4 a.m.	345	293	297	231	210	197	208	222	252	314	332	345	3246
*6 a.m.	398	341	349	278	260	241	264	272	303	367	383	397	3853
*8 a.m.	451	389	383	286	266	241	264	291	328	400	430	448	4177
*9 a.m.	478	395	383	286	266	241	264	291	328	404	446	476	4258
To one hour after Sunrise from:													
*6 a.m.	80	54	34	8	6			19	25	37	63	79	405
*7 a.m.	54	31	7						13	20	39	53	217
*8 a.m.	27	6								4	16	28	81

Allowance has been made for Normal British Summer Time and for the usual Bank Holidays.

* Lights are assumed to be switched off one hour after sunrise.

ELECTRICITY

...es and Notes indicating Approximate Lamp Sizes in Appropriate Fittings necessary at various Mounting Heights and Spacings

Reprinted from Appendix 2 of the Lighting Committee's Report

...able 1.—Illumination of approximately 6 foot-Candles at a height of 3 feet above the Floor (i.e., Bench Level)

Using Tungsten Filament Lamps

...pe and Size of Lamp. Watts.	Standard Dispersive Reflectors. Mounting Height. Above Bench.		Above Floor.		Maximum Distance between Adjacent Reflectors.		Concentrating Reflectors. Mounting Height. Above Bench.		Above Floor.		Maximum Distance between Adjacent Reflectors.	
	Ft.	In.	Ft.	In.	Ft.	In.	Ft.	In.	Ft.	In.	Ft.	In.
...0 Coiled-Coil	6	6	9	6	9	6	—		—		—	
...0 Tungsten	8	0	11	0	12	0	—		—		—	
...00 Tungsten	10	0	13	0	14	6	—		—		—	
...00 Tungsten	12	0	15	0	18	0	17	0	20	0	17	0
...00 Tungsten	17	0	20	0	25	0	24	0	27	0	24	0
...50 Tungsten	22	0	25	0	32	0	30	0	33	0	30	0
...000 Tungsten	24	0	27	0	36	0	36	0	39	0	36	0
...500 Tungsten	30	0	33	0	45	0	45	0	48	0	45	0

Using Gaseous Discharge Lamps

...ype and Size of Lamp. Watts.	Industrial Reflectors. Mountaig Height. Above Bench.		Above Floor.		Maximum Distance between Adjacent Reflectors.	
	Ft.	In.	Ft.	In.	Ft.	In.
...0 Tungsten Mercury	14	0	17	0	21	0
...00 Tungsten Mercury	20	0	23	0	30	0
...80 Mercury . .	10	0	13	0	14	6
...25 Mercury . .	12	0	15	0	18	0
...50 Mercury . .	17	0	20	0	26	0
...00 Mercury . .	24	0	27	0	36	0
...45 Sodium . .	9	0	12	0	13	0
...60 Sodium . .	11	0	14	0	16	0
...85 Sodium . .	14	0	17	0	21	0
...40 Sodium . .	18	0	21	0	27	0

TABLE 2.—ILLUMINATION OF APPROXIMATELY 2 FOOT-CANDLES AT HEIGHT OF 3 FEET ABOVE THE FLOOR (i.e., BENCH LEVEL).

Using Tungsten Filament Lamps.

Type and Size of Lamp. Watts.	Standard Dispersive Reflectors. Mounting Height. Above Floor.		Standard Dispersive Reflectors. Maximum Distance between Adjacent Reflectors.		Concentrating Reflector Mounting Height. Above Floor.		Concentrating Reflector Maximum Distance between Adjacent Reflectors.	
	Ft.	In.	Ft.	In.	Ft.	In.	Ft.	In.
300 Tungsten .	—		—		31	0	31	0
500 Tungsten .	30	0	42	0	40	0	40	0
750 Tungsten .	35	0	52	0	47	0	47	0
1,000 Tungsten .	40	0	60	0	53	0	53	0
1,500 Tungsten .	47	0	70	0	68	0	68	0

Using Gaseous Discharge Lamps

Type and Size of Lamp. Watts.	Industrial Reflectors. Mounting Height. Above Floor.		Industrial Reflectors. Maximum Distance between Adjacent Reflectors.		Concentrating Reflectors. Mounting Height. Above Floor.		Concentrating Reflectors. Maximum Distance between Adjacent Reflectors.	
	Ft.	In.	Ft.	In.	Ft.	In.	Ft.	In.
300 Tungsten Mercury .	—		—		35	6	35	6
500 Tungsten Mercury .	34	0	50	0	45	0	45	0
125 Mercury .	—		—		31	0	31	0
250 Mercury .	30	0	42	0	—		—	
400 Mercury .	40	0	60	0	—		—	
85 Sodium .	30	0	35	0	—		—	
140 Sodium .	30	0	45	0	—		—	

TABLE 3.—ILLUMINATION OF APPROXIMATELY 0·5 FOOT-CANDLES IN CORRIDORS AND STAIRCASES.

Size of Lamp. Watts.	Height above Floor.		Maximum Distance between Reflectors.	
	Ft.	In.	Ft.	In.
40	10	0	20	0
60	15	0	30	0
75	17	0	34	0
100	20	0	40	0

For stairways, lighting points will usually be on each landing and h landing.

NOTES.—*These tables have been prepared primarily to assist in checking ing lighting installations. Other factors are involved in problems of design new installation or improvements should only be carried out in conjunction expert advice.*

n using the tables it should be noted that :

(i) The use of efficient modern types of reflectors and lamps made to comply with British Standard Specification is assumed. For other types of equipment allowances must be made for the different performances obtained. If the reflectors are shallow and unsuitable or dirty or the lamps aged, considerably lower intensities will result.

(ii) The mounting heights are minima for the spacings given. They may be somewhat exceeded, keeping the spacing the same, without materially affecting the illumination on the working plane. In cases of doubt measurement should be made with a light-meter.

(iii) Comparisons between tungsten filament and gaseous discharge lighting should include relative costs and life of equipment and considerations of colour perception.

(iv) Working conditions are usually improved if some light is cast upon light ceilings and upper parts of walls.

CONVERSION TABLES

umination

1 Foot-candle = 10·76 Lux
1 Lux = 0·093 Foot-candle.

ightness

1 Candle per sq. in. = 452·4 equivalent foot-candles (foot-lamberts).
= 0·4869 lamberts = 486·9 milli-lamberts.

pproximate Metric Equivalents

To Convert	British to Metric. Multiply by	Metric to British. Multiply by
nches—Millimetres	25·40	0·0394
Feet—Metres	0·3048	3·2808
Yards—Metres	0·9144	1·0936
Miles—Kilometres	1·6093	0·6214
Sq. ins.—Sq. cms.	6·4516	0·1550
Sq. ft.—Sq. metres	0·0929	10·7639
Cu. ins.—Cu. cms.	16·387	0·0610
Cu. ft.—Cu. metres	0·0283	35·3148
Ocean tons—Cu. metres	1·132	0·8834
Pounds (av.)—Kilogrammes	0·4536	2·2046
Tons (av.)—Tonnes	1·0160	0·9842
Gallons—Litres	4·5459	0·2199
Lbs./in.^{2}—Kg/cm.^{2}	0·0703	14·2230
Tons/in.^{2}—Kg./mm.^{2}	1·5749	0·6349
Gals./min.—Cu. metres/hr.	0·2728	3·6662
Cu. ft./min.—Cu. metres/hr.	1·6990	0·5886
Inches Hg.—Kg./cm.^{2}	0·0344	29·0427

Temperature Conversion

Temperature ° C. = (Temp. ° F. − 32) × $\frac{5}{9}$
Temperature ° F. = (Temp. ° C. × $\frac{9}{5}$) + 32
Temperature rise ° C. = $\frac{5}{9}$ Temperature rise ° F.
Temperature rise ° F. = $\frac{9}{5}$ Temperature rise ° C.

Miscellaneous

Column of water 2·31 ft. high = 1 lb. per sq. in.
1 Cubic ft. of water per second = 373·8 gallons per min.
1 Cubic ft. of water weighs 1,000 ozs. = 62·5 lbs.
1 Gallon of water weighs 10 lbs.

1 Therm = 100,000 B.Th.U. = 29·34 kWh.
1 H.P. = 746 watts 1 kW. = 1·34 H.P.
1 B.Th.U. = 778 ft. lbs.

$$\text{Torque in lb. ft.} = \frac{\text{H.P.} \times 5250}{\text{R.P.M.}}$$

INDEX

A

dents :
alysis of, 26
used by faulty lighting, 24–25
used by shadows, 27–28
uses of, 26–27
limination of, 24
alls on stairs, 28
echanical causes, 24
inor accidents, 25
rsonal causes, 24
eduction of, 23
eportable, 23
atistics, 23
orkers' responsibility, 24
ident rate, Relation between and illumination, 25
quacy of lighting, 89
lysis of installation in :
ero-engine works, 8
all-bearing works, 10
otton mill, 9
oundry, 10
gle elliptical reflectors, Mounting data, 62–64
endices, Index to, 99
embly processes, 90–98
omatic control of lighting, 31

B

nds, 30
ghtness, Definition of, 100

C

Candle-power, Definition of, 100
Carbon arc lamps, 14
Carbon filament lamp, 32
Chemical works, Certificate of exemption for, 87
Choke, 36
Cleaning costs, 76
Cleaning lamps and reflectors, Method of, 75–76
Cleanliness, 23, 74–76
Coefficient of utilization, Definition of, 100
Coefficient of utilization, Table of, 110
Coiled-coil filaments, 33–34
Coiled filaments, 33–34
Colour quantity, Variation of, 21
Colour, Reflection values of, 22
Colours, Blending of, 37
Concentrating units, Mounting and spacing data, 54–55, 60–61
Condenser, 36
Coolidge, Dr. W. G., 32
Current ratings, Tinned wire and standard alloy wire, 113
Cut-off angle, 55

D

Daylight, Distribution of, 30
Daylight, Reflection of, 30

Departmental Committee on Lighting:
  Extracts from Fourth Report of, 81–82
  Extracts from Fifth Report of, 82–84
  Report of, 53
Depreciation factor, Definition of, 101
Design of lighting installation, 53–74
Diffused lighting, 55
Diffuser reflectors, Mounting and spacing data, 64–65
Diffusing glass globes, 55
Diffusion and reflection, Definitions of, 102
Dimensions and ratings of electric discharge lamps, 116–117
Direct lighting—small-area units, 54
Dispersive reflectors, Mounting and spacing data, 58–59
Distributing units, 54–55

E

Edison, Thomas, 31
Efficiencies of light sources, 32
Electrical energy wasted, 37
Electric discharge lamps:
  Dimensions and ratings of, 116–117
  Explanation of function, 34
  Limiting current flowing in, 36
Electric lamp:
  First patent granted, 31
  Historical importance, 31
  Manufacturers Association of Great Britain, 70
  Method of calculating mounting height and spacing, 70–72
  Purpose of, 31
Environment, 25
Exemption, Certificates of, 86–87
Explosives works, Certificate of Exemption for, 87–88
Eyes:
  Adaptability, 14, 27
  Adjustment to contrasting illumination, 21
  Causes of fatigue, 26
  Controlled production test, 27
  Dangers of contrast in illumination, 21
  Decreased ability to see, 27
  Development of, 12
  Effect of lighting on, 25
  Focusing power, 27
  Mental influence, 13, 24–25
  Position during periods of rest
  Process of perception, 12
  Strain, 23

F

Factories Act, 1937, Section 5, 81
Factories (Standards of Lighting) ulations, 1941, 85–87
Factory Installation, A typical ample, 90–95
Factory Lighting Code, 90
Faraday, Michael, 31
Fatigue, Causes of, 25–26
Field of vision, 20, 21
Filaments: 33
  Coiled and coiled-coil, 33–34
  Tantalum metal, 32
  Tungsten, 32
Fluorescence, Explanation of, 37
Fluorescent analine substances, 37
Fluorescent lighting:
  Constituents of, 39
  Polyphase system, 43
  Single phase system, 43
  Split phase system, 43
  Types of systems, 43
Fluorescent materials, Use of, 38
Fluorescent tubular lamps: 28, 3(
  Auxiliary equipment, 40
  Characteristics of, 38
  Colours of, 39
  Detecting and correcting faults in
  Influence of ambient temperatu 41–42
  Life of, 44–45
  Maintenance of, 80, 114–115
  Operating details, 38–41
  Reasons for dimensions, 39
  Schedule of symptoms, causes remedies, 114–115
  Starter switch and its requireme 40
  Stroboscopic effect and its reme 43–44
  Thermal glow switch, 40

-candle :
finition of, 101
umination required, 53–54
tensities for industrial interiors, arranged alphabetically, 103–109
perating values recommended, 103–109
tatutory requirements, 85–86
alues, 28
wires, Table showing fusing current in amperes, 112

G

-filled lamps, 32–33
eral diffused lighting, 55
eral illumination, Statutory regulations, 85
re : 16–22, 27
rightness at source, 19
y reflection, 21
omparative standards, 17
ontrast with background, 20
aylight, 30
efinition of, 16
ye exposed to, 16
actors affecting, 19
ight sources classified for, 18–19
bjections to, 16
uality and quantity, 16
tatutory regulations, 86
upplementary light sources, 19
ystem of rating, 17
ime of exposure, 21
otal volume of light, 19
Vrong position in field of view, 20

H

urs employed, Statutory regulations, 85
urs of lighting in a year, 118

I

uminating engineer, Aims of, 31
Incandescent lamps :
Rating and efficiency of, 116
Their spectra, 13
Indirect lighting, 55–56
Industrial requirements, Survey of, 120
Operations arranged alphabetically, 45–53
Inspection process, 90–98
Installation :
Angle elliptical reflectors, Mounting data, 62–64
Choosing the lighting unit, 54–56
Concentrating reflector, Mounting and spacing data, 60–61
Concentrating units, 54–55
Cut-off angle, 55
Designing, 53–74
Diffuser reflectors, Mounting and spacing data, 64–65
Diffusing glass globes, 55
Distributing reflectors, Mounting and spacing data, 69
Distributing units, 54–55
Durability of, 8
Foot-candle illumination required, 53–54
Fundamentals, 53
General diffused lighting, 55
Indirect lighting, 55–56
Inspection department, 97
Lamp size, Calculation required to find, 72
Local lighting, 54–56
Local lighting reflectors, Mounting and spacing data, 65, 67
Loss of initial efficiency, 54
Machine shop, 94–95
Method of planning, 11
Mounting and spacing data, 56–72
Parabolic angle reflectors, Mounting and spacing data, 67–69
Press shop, 93
Radio factory, 90–98
R.L.M. dispersive reflector, Mounting and spacing data, 58–59
Semi-direct units, 55
Sheet metal shop, 95
Tool designing department, 91
Tool making department, 91
Typical example of planning, 72–74
Vertical elliptical reflectors, Spacing data, 61–62

Interior surfaces, 20
Interior surfaces, Dirty, 22
Interior surfaces and morale, 22

L

Lamp size, Calculation required to find, 72
Lamps:
  Dead, and empty sockets, 77
  Electric discharge, 34
  Electric discharge, Limiting current flowing in, 36
  Filaments of, 33
  Fluorescent tubular, 36–45
  Gas-filled, 32, 33
  Life of, 33
  Mercury discharge, 33, 35
  Poor quality, 77
  Sodium discharge, 33, 36
Langmuir, Dr. Irving, 32
Life of lamps, 33
Light:
  Automatic control of, 31
  Definition of, 101
  Effect on worker, 25
  From the sun, analysed, 37
  Measuring quantity of, 28–29
  Psychological effect of, 29
  Purpose of, 12–16
  Retards fatigue, 25
  Sources of, 30–36
  Total volume of, 19
Light and safety, Relation between, 23
Light sources:
  Classified for glare, 19
  Distance from eye, 20
  Efficiencies of, 32
  Grades of, 18
  Supplementary, 19
Lighting engineers, Facts for, 7–11
Lighting unit, Selecting, 54–56
Light meter, Use of, 28–29
Local Lighting, 54, 56
  Dangers of without general lighting, 20
  Reflectors, external type, 65, 66
  Reflectors, internal type, 66, 67
  Statutory regulations, 86
Louvres, 30
Lumen, Definition of, 101
Lux, Definition of, 101

M

Machine shop, 94
Machines, painted, 22
Maintenance, 74–80
  Comparison between soiled clean reflectors, 75
  Dead lamps and empty sockets,
  Fluorescent tubes, 80, 114–115
  Necessity of proper reflector, 79
  Old lamps, Loss caused by, 77–
  Planned periodic attention, 79
  Poor quality lamps, 77
  Soiled lamps and reflectors, 74,
  Soiled walls, Loss of reflecting p caused by, 76–77
  Under-voltage burning, 79
Mechanical causes of glare, 24
Mental impressions, 24–25
Mercury discharge lamps, Explana of function, 35
Metric equivalents, Table indicat 121
Minimum recommended standards general lighting, 81–85
Moleyns, Frederick de, 21
Monochromatic light, 14
Morale, Improved, 23
Mounting height and spacing d 56–72
  Method of calculating, 70–72
  Tables indicating, 119–120

N

Natural light, 30–31, 37

O

Old lamps, Loss caused by, 77–78

P

nt, Light-reflecting, 22
rabolic angle reflectors, Mounting and spacing data, 67–69
ssages :
Illumination of, 30–31
Table of mounting heights and spacing, 120
rsonal causes of accidents, 24
oto-electric relay, 31
anning a lighting installation, 53–74
lyphase system, 43
esses, Illumination of, 93–94
oduction, Increased, 23
oduction process, 90–98
oduction test, 27
rpose of lighting, 12–16

R

ting and efficiency of incandescent lamps, 116
ting schedule, 9
flected light, 16
flection factors, 72
flective powers of different surfaces, 76–77
flection of daylight, 30
flector types, Index of, 57
flectors :
Mounting and spacing data, 56–72
Value of, 79
quirements of factory executive, 7
om index, Table for finding, 71, 111
oyal Society for the Prevention of Accidents, The, 24

S

fety, 22, 23
fety engineering, 24
fety officer, 24
mi-direct units, 55
adow avoidance, Statutory regulations, 86
adows, Confusion caused by, 28
eet metal shop, 95
ngle phase system, 43
Sodium discharge lamps, Explanation of function, 33, 36
Soiled lamps and reflectors, 74–76
Soiled walls, Loss of reflective power caused by, 76–77
Sources of light, 30–36
Spacing and mounting heights, Table indicating, 119–120
Spectra :
Continuous, 13
Discontinuous, 14
Standards of illumination, Recommended, 29
Starter switch for fluorescent tubes, 40
Statutory regulations : 81–90
Certificate of exemption, 86
Chemical works, Certificate of exemption for, 87–88
Cut-off prescribed, 86
Factories (Standards of Lighting) Regulations, 1941, 85–87
Factories to which Factories (Standards of Lighting) Regulations, 1941, do not apply, 87
Foot-candles required, 85–86
General illumination, 85
Glare, 86
Hours employed, 85
Letter sent to employers, 88–89
Local lighting, 86
Reflection from light-coloured surroundings, 89
Scope of the Regulations, 88
Shadow avoidance, 86
Standards of suitability, 89
Sufficiency of illumination, 88–89
Statutory Rules and Orders, 1941, No. 94, 24, 85–87
Stroboscopic effect and remedy, 42–44
Suitability of lighting, 90
Supervision simplified, 23
Supplementary lighting, *see* Local lighting
Swan, Sir Joseph, 31

T

Temperature conversion, 122
Thermal glow switch, 40
Tool designing department, 91

Tool-making department, 91
Transformers, 36
Tungsten filaments, 32

U

Under-voltage, Loss caused by, 79
Units and terms, Definitions of, 100–102

V

Vertical elliptical reflectors, Spacing data, 61–62
Vertical surfaces, Lighting of, 63–6
Visibility :
Factors determining, 26
Meter, 29
Visual tasks, Of extreme accuracy, 92
Voltage, Variation in line, 41

W

White surfaces, Advantages of, 15
Windows : 30
Advantages of large, 15
Workmanship, Greater accuracy, 23